Study of Variations in Calibration Factor of a Charcoal Canister Based Passive ^{222}Rn Detector with Relative Humidity

Poornima S[1], Karunakara N[2], E D D'Silva[1]

1. Department of Physics, Centre for PG Studies & Research
   St Philomena College, Puttur
2. Centre for Advanced Research in Environmental Radioactivity (CARER),
   Mangalore University
   Email: spoornimas96@gmail.com

Abstract: *Many active, passive measurement techniques are used to measure the ^{222}Rn concentration around the world. The devices and detectors used for these techniques in India are most of the times factory calibrated or else calibrated in an accumulation kind of calibration chambers individually. Hence there is a need for simultaneous calibration of all these detectors at a single instant for various simulated conditions of ^{222}Rn concentration, humidity and temperature. In the present study calibration method of charcoal based detector is discussed.*

Key Words: *Radon, Charcoal, Humidity, Calibration.*

1. Introduction

Radon (^{222}Rn) is a radioactive gas that emanates from rocks and soils and tends to concentrate in the enclosed spaces like underground mines or houses. Soil gas infiltration is recognized as the most important source of residential ^{222}Rn. Other sources, including building materials and water extracted from wells, are also important in some circumstances (D. Mazur *et al*, 1999).

^{222}Rn is a decay product from the uranium (^{238}U) decay series. It is an inert gas having half-life of 3.8 days. Another member of ^{222}Rn isotope family is Thoron (^{220}Rn), having half life of 55.6 second and chemical properties same as that of ^{222}Rn. The decay products of ^{222}Rn and ^{220}Rn are the isotopes of heavy metals namely ^{x}Po, ^{x}Bi and ^{x}Pb are solid and behave as airborne particles (A. Vargas *et al*, 1990; David J. Gray, Sam T. Windham, 1987).

Many instruments and techniques are available for the measurement of ^{222}Rn, ^{220}Rn and their decay products. These measurement techniques are based on the detection of alpha, beta or gamma ray radiations emitted by them independently or in combination.

Many active, passive measurement techniques are used to measure the ^{222}Rn concentration around the world. Active monitoring devices such as

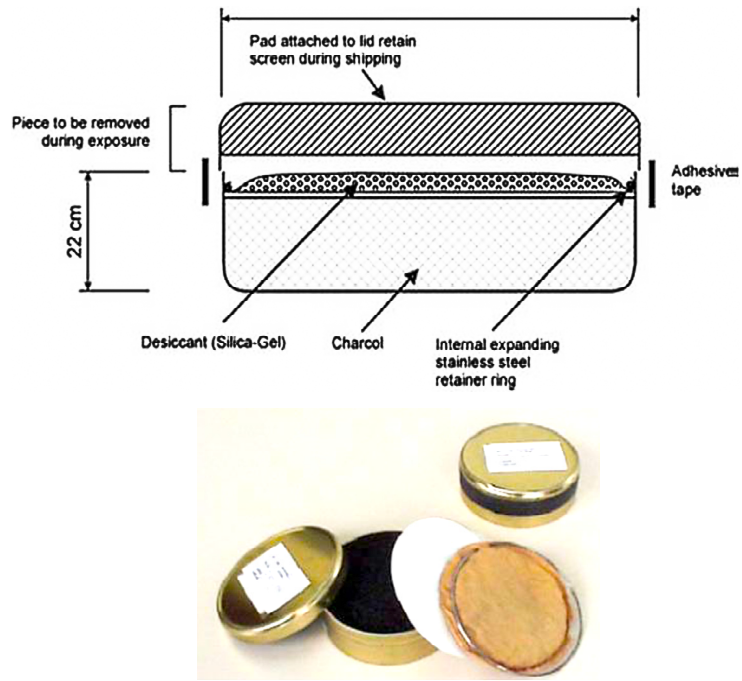
Alpha Guard, scintillation based Rn^{222}/Rn^{220} monitors (SRM, TM), RAD7 etc and passive techniques such as pinhole dosimeters, SSNTD based DTPS/ DRPS etc (Jon Miles, 2006) are widely used in India. Hence devices and detectors used for these techniques in India are most of the times factory calibrated or else calibrated in an accumulation kind of calibration chambers individually. Hence there is a need for simultaneous calibration of all these detectors at a single instant for various simulated conditions of ^{222}Rn concentration, humidity and temperature.

The present study describes the calibration of charcoal based detector. The Objective of the study is to determination of the calibration factor K for the charcoal based detectors for different exposure relative humidity conditions.

2 Materials and Methods

2.1 ^{222}Rn Canister Detector

Fig 1: Scheme and Photograph of Canister



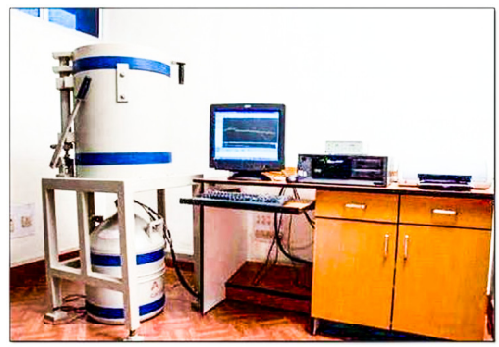
The ^{222}Rn canister detector containing 75 g of granular activated charcoal of mesh size (8 x 16 meshes) coated with a 50-g Silica Gel drier-barrier. The dimension of the canister is 4"×11/8"H. Figure 1 shows a scheme of the canister and a photograph. By counting the gamma pulses of energy for Pb-214 (295 keV, 352 keV) and Bi-214 (609 keV) in an HPGe gamma spectrometer, the amount of adsorbed ^{222}Rn in the activated charcoal is measured.

2.2 High Pure Germanium (HPGe) Detector

Hyper pure germanium detectors (Figure 2) are widely used for gamma ray spectroscopy to determine quantitatively the activities of natural ^{40}K, ^{232}Th, ^{238}U, ^{226}Ra, ^{210}Pb, & ^{137}Cs in the environmental samples. The HPGe detectors have very high resolution, but the efficiencies are low compared to those of scintillation detectors such as NaI (Tl). The high purity germanium detector can be produced from either n-type or p-type (Germanium) semiconductor materials. Since germanium has a relatively low band gap, these detectors must be cooled in order to reduce the thermal generation of charge carriers (reverse leakage current). Otherwise, the leakage current induced noise destroys the energy resolution of the detector. Therefore, the HPGe detector should always be operated at liquid nitrogen temperature (-196^{0}C or 77K).

Here we analyze the Rn^{222} absorbed canister in HPGe for 1200 seconds after a delay of 3 hours post exposure and ceiling the detectors, then the counts obtained at energy peak corresponding for Pb-214 (295 keV, 352 keV) and Bi-214 (609 keV) are used for calculating the calibration factor K.

Fig 2: A View of HPGe Spectrometer Used in Present Study



3 Experimental

The ^{222}Rn canister detector containing 75 g of granular activated charcoal of mesh size (8 x 16 meshes) coated with a 50-g Silica Gel drier-barrier. The dimension of the canister is 4"×11/8"H. Figure 1 shows a scheme of the canister and a photograph.

The calibration factor K is calculated using the following equation:

$$K = \frac{NC_{\gamma}.\lambda_{Rn}^{2}}{\varepsilon.C.(1-e^{-\lambda_{Rn}.T}).(1-e^{-\lambda_{Rn}.\Delta t}).e^{-\lambda_{Rn}.t}} \qquad (1)$$

Where NCγ- total γ-count minus the background counts, t - time from the end of the exposure period and the start of the counting period or decay time, Δt- Counting period, ε - Detection efficiency, λ_{Rn}- ^{222}Rn decay constant in s^{-1}, C_{Rn}- Activity mean ^{222}Rn concentration in chamber air during the exposure period in Bq/m^3, K - Calibration factor and represents the mean adsorption rate for ^{222}Rn during the exposure period per unit air ^{222}Rn concentration (expressed in Bqs^{-1} per Bqm^{-3} or m^3s^{-1}).

In the present study a set of exposures under different environmental conditions were done in response to relative humidity, temperature and ^{222}Rn concentration. The charcoal adsorption technique is widely used to measure indoor ^{222}Rn concentration for periods of 2-7 days. Such short term measurements are commonly carried out in order to provide both cost effective and rapid results. During the exposure time, ^{222}Rn is continually adsorbed and desorbed. The adsorption and desorption process depends on several factors. The most important is the air humidity since charcoal adsorbs water and ^{222}Rn atoms have fewer sites to be adsorbed.

3.1 General Protocol for Calibration

At least 10 dosimeters of each type should be placed in the chamber for exposure. Using a suitable source, ^{222}Rn concentration in the chamber is generated to required level. Other parameters of the chamber such as humidity, temperature and fan off – on conditions are also set as per the requirements. Dosimeter exposure duration varies from 3-7 days. Charcoal canisters here were exposed for 3 days as the exposure duration selected is justified to account for unexplainable variations in measurements. Once the exposure duration is complete, dosimeters are processed and monitor data is analyzed, respective calibration factors and percentage of deviation from the set values

in case of online monitors are given (J. Bogacz, *et al* 2001; Lalmuanpuia Vanchhawng, 2012)

^{222}Rn detectors should be calibrated annually in a qualified ^{222}Rn chamber. The ^{222}Rn chamber exposures should be done at different ^{222}Rn concentrations and with various environmental conditions as humidity, temperature and exposure duration. This should be done periodically and specifically before a new batch of charcoal is put into use. The data obtained should be compared to the data originally for quality assurance purposes.

In order to evaluate the influence of relative humidity over the calibration factor of ^{222}Rn for the charcoal based detectors, 4 exposures inside the ^{222}Rn chamber were carried out under different humidity conditions ranging from 50% to 80%, keeping the ^{222}Rn concentration fixed at ~ 10000 Bqm^{-3} and temperature at 28^{0}C. In each run at set of 6 canisters & vials were exposed for a period of 3-days at certain fixed positions in the chamber. The exposed canisters and vials are sealed and then analyzed using HPGe gamma spectrometer, after placing for a delay period of 3 h in order to ^{222}Rn attain secular equilibrium with its daughter products.

By counting the gamma pulses of energy for Pb-214 (295 keV, 352 keV) and Bi-214 (609 keV) in an HPGe gamma spectrometer, the amount of adsorbed ^{222}Rn in the activated charcoal is measured in units of Becquerel. Which then upon substitution in the equation (1) along with the decay terms and ^{222}Rn concentration maintained in the chamber, gives the values of the calibration factor K. Similarly the detectors are exposed at different relative humidity values and the calibration factor is calculated each time. Mass gained by the detectors is also measured during all the exposures and its dependency over the exposure relative humidity is analyzed by deducing a correction factor to the calibration factor. The exponential fit to the curve representing variations in calibration factor K versus mass increment Δm for the respective value of relative humidity gives the correction factor.

3.2 Specifications of the Chamber Used for Calibration

In order to study the variations of the calibration factor with humidity, the canisters were exposed to controlled environmental conditions in a walk in ^{222}Rn calibration chamber installed at CARER, Mangalore University (figure 3). The specifications of the chamber are given in the Table. 1 below (Paul Kotrappa and Frederick Stieff, 2007)

Table 1: Specifications of the Chamber Used for Calibration

Volume	22.7 m^3
Dimensions	3 m (*l*) × 2.75 m (*w*) × 2.75 m (*h*)
Temperature control range	5 °C – 50 °C
Relative humidity control range	30 % - 95 %
Inlet gas ports	5
Exhaust gas ports	1
Sampling ports	5
Chamber wall composition	Double walled SS sheets with 100 mm thick thermal insulation of polyurethane foam filled in between the sheets.
Detectors/ instrument placers	SS platforms, holders & rods
Humidifier	Ultrasonic & boiler type humidification system
Dehumidifier	Refrigerated coil type
Temperature controller	Heated and refrigerated coils

In three of the four chamber walls there are access ports in order to take air samples, ventilate the chamber and for the necessary electrical connections.

Fig 3: Walk in Type ^{222}Rn Calibration Chamber

The reference instruments for the ^{222}Rn concentration measurements in the chamber are ionization chamber based Alpha Guard and scintillation cell based RnDuo, whereas soil gas is used as ^{222}Rn source.

4 Results and Discussions

In tables given below the different environmental conditions in the ^{222}Rn chamber for each exposure and the calibration factor estimation are presented. For each exposure calibration factor K has been estimated using equation (1). Four exposures were carried out in order to evaluate the effect of relative humidity on the calibration factor. Charcoal canisters and vials were exposed to relative humidity of 50%, 60% and 80%. Rn^{222} concentration and temperature are almost same for each exposure, while relative humidity varies from 50% to 80%. Calibration was done by maintaining a constant temperature of 28^0C.

Table 2: Environmental Conditions in the ^{222}Rn Chamber for Each Exposure and the Calibration Factor Estimation for Charcoal Canister

Relative humidity (%)	^{222}Rn Calibration factor $K*10^{-11}(m^3s^{-1})$	Mass increment in the canister after exposure Δ m(g)
50	7.96	2.0885
60	8.20	6.9000
80	2.19	18.871
Environmental exposure	13.1	3.3630

Table 3: Environmental Conditions in the ^{222}Rn Chamber for each Exposure and the Calibration Factor Estimation for Vials.

Relative humidity (%)	^{222}Rn Calibration factor $K*10^{-11}(m^3s^{-1})$	Mass increment in the vials after exposure Δ m(g)
60	1.70	0.3500
80	0.177	0.6200
Environmental exposure	1.39	0.0705

Fig 4: Correlation Plot Showing Variation in Calibration Factor K with Relative Humidity for Charcoal Canister.

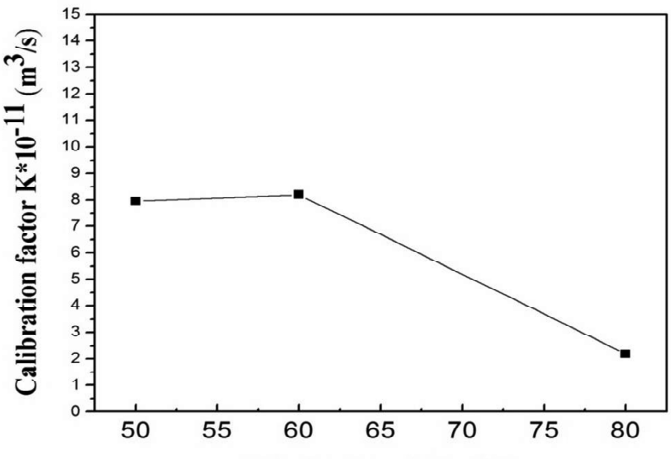
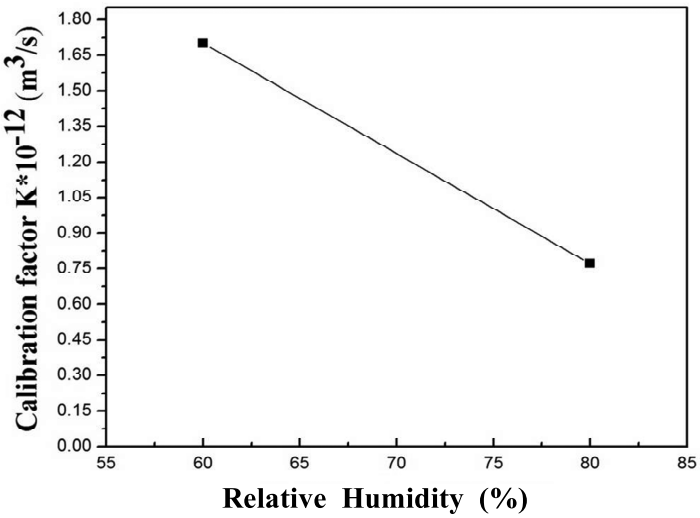


Fig 5: Correlation Plot Showing Variation in Calibration Factor K with Relative Humidity for Vials.



From the Figure 4 and 5 we can infer that as the relative humidity increases the pores of the charcoal gets filled with moisture, which impairs its capacity to adsorb ^{222}Rn as the result the calibration factor values decreases with increase in the relative humidity at exposure. The calibration factor obtained in case of vials is smaller by an order than that of canister and this is due to the fact that canister have higher amount of charcoal and greater surface area of exposure when compared to vials.

From Table 2 and Table 3 it is evident that a variation of the calibration factor K with relative humidity and variations in mass increment (Δm) in the detector with relative humidity is occurring. Hence a correction factor due to mass increment needs to be incorporated in addition to calibration factor; this is also suggested in the calibration experiments carried out described in Vargas *et al* 2006 and a relation of the kind as expressed in the following is expected.

$K = 1.363\times10^{-6}e^{-0.01225\,\Delta m}$, where Δm is the mass increase during the exposure period in grams and accordingly the correction factor is estimated for the detectors. This procedure of fitting exponentially to deduce the correction factor needs some more experimental results, and is not discussed in this article.

5 Conclusion

Calibration of passive activated charcoal based Rn^{222} detectorsis done in a walk in calibration chamber installed at CENTRE FOR ADVANCED RESEARCH IN ENVIRONMENTAL RADIOACTIVITY (CARER), Mangalore University. Similarly periodic calibrations can be done for different kind of detectors used for Rn^{222} measurements in the facility before its field validation.

References

A. Vargas, X. Ortega, L. Serrano. (1990). Response of a ^{222}Rn Canister to Climatic an ^{222}Rn Variations in the INTE ^{222}Rn Chamber, *Health Phys*., 58: 583-589.

David J. Gray, Sam T. Windham. (1987). EERF Standard Operating Procedures for ^{222}Rn Measurement Using Charcoal Canisters.

Jon Miles. (2004). Methods of ^{222}Rn Measurement and Devices, *INIS*, 36(3)

D. Mazur, J. Bogacz, J. Swakon, Loskiewicz, P. Olko, M. Janik. (1999). Measurements of ^{222}Rn Concentration in the Dwellings and Soil at the Institute of Nuclear Physics in Krakow, *Radiation Measurements*, 33(6): 873-878.

J. Bogacz, D. Mazur, J. Swakon, M. Janik. (2001). The Calibration of activated charcoal detectors in a small ^{222}Rn exposure chamber, Radiation Measurements, 33(6): 873-878.

Lalmuanpuia Vanchhawng. (2012). Experiment to Find the Calibration Factor for ^{222}Rn and ^{220}Rn Using Sources of Known Activity.

Paul Kotrappa and Frederick Stieff. (2007). Characterization and Use of an Accumulating Type of ^{222}Rn Test Chamber.