Journal homepage www.jzs.univsul.edu.iq
Journal of ZankoySulaimani
Part-A- (Pure and Applied Sciences)

The diffusion coefficient and calibration factors for indoor radon measurement in bare and twin cup modes

Ali F. Nadir, Jabbar H. Juber, Abdul Ridha H. Subber and Noori H.N. Al-Hashimi

Department of Physics, college of education for pure science university of Basrah, Basrah, Iraq

Email: abdulsubber1948@gmail.com

Article info

Original: 17 May. 2015
Revised:23 July. 2015
Accepted:30 August. 2015
Published online: 20 March. 2016

Key Words:
Radon
Calibration factor
Diffusion factor
Transmission factor
twin cup

Abstract

The calibration factor and diffusion are essential parameters in the solid state nuclear track detectors dosimeters. In the present work, experiments were carried out to measure the calibration factors for different modes of measurement in indoor radon dosimetry and diffusion coefficient of gas filter used in the experiments. The calibration chamber provides with standard radium source and radon vision instrument, was used as hybrid combination between active and passive methods. The calibration factor was determined through the relation between standard radon concentration, track density and exposure time. The values of calibration factors was 0.020±0.005 Tr.cm^{-2}/Bq.m^{-3}.d for sponge cup mode, 0.021±0.006 Tr.cm^{-2}/ Bq.m^{-3}.d for filter cup mode and 0.029±0.008 Tr.cm^{-2}/ Bq.m^{-3}.d for bare mode respectively. The calibration factor for bare CR-39 was found to be 0.384±0.102 Tr.cm^{-2}/ Bq.m^{-3}.d. The diffusion coefficients are 7.1x10^{-13} m^2/sec for filter paper and 4.6x10^{-9} m^2/sec for sponge. The calibration of SSNTDs using hybrid method between active and passive can be used to minimize the uncertainty in the calibration factors.

Introduction

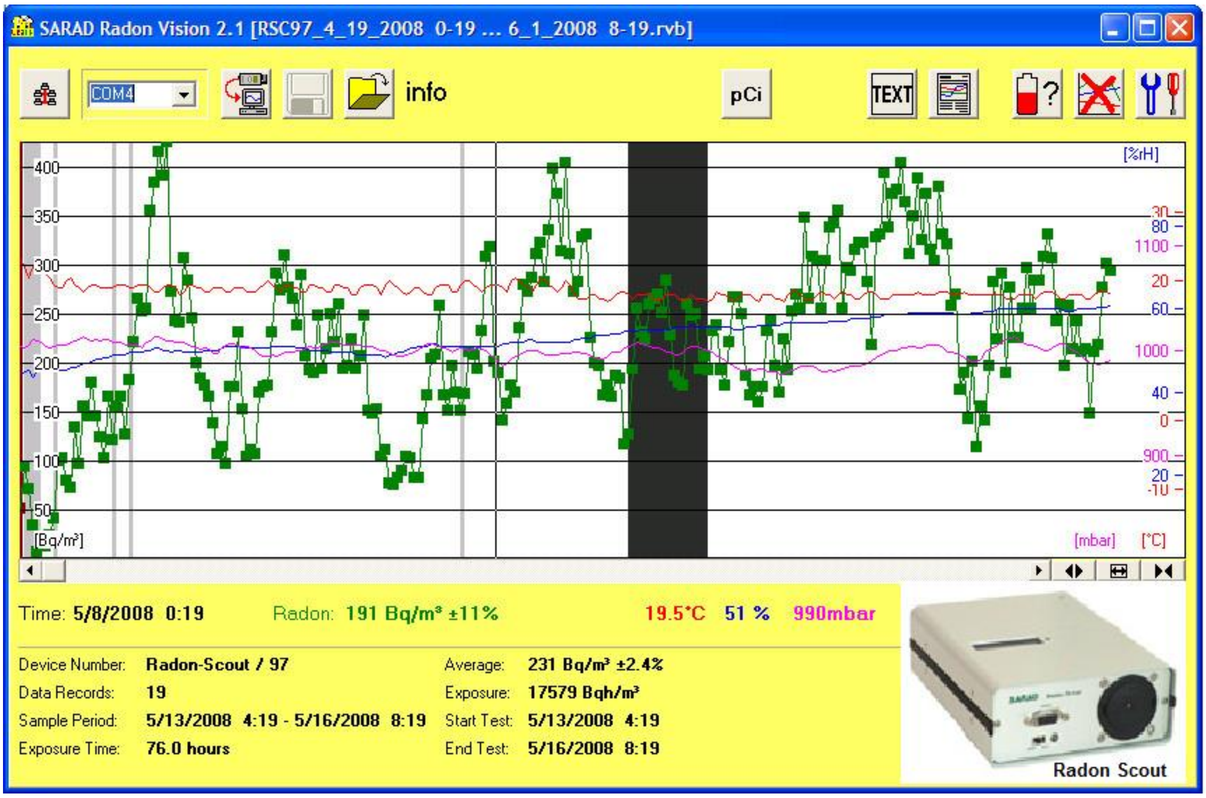
Solid State Nuclear Track Detectors (SSNTDs) has been used for many decades of detecting alpha particles emitted from natural radioactive decay series [1-7]. Charge particle leaves narrow damage trials during their passage through detector (latent tracks). These tracks are making visible for a microscope by using chemicals etching. The track density rate per unit area converted to alpha particle concentration per meter cubic by a conversion factor called the Calibration Factor (CF). The calibration factors (CFs) are the quantities, which are used to convert observed track density rates of activity concentration of species under study. Many attempts have been made to calculate and measure CF factors [8-14]. Different modes of calibration experiments have been performed in many radiation centers [15-18]. The calibration factor estimated experimentally as well as theoretically for different modes of simulations. Even though SSNTDs give a better long – term average of radon concentration, and to make accurate meaningful measurement using any of the measuring techniques, it is necessary to calibrate the detector under known radon activity concentration usually within an enclosed purpose built radon chamber [14].

The present work was performed for measuring the calibration factor of LR-115 type-II, used in the indoor twin cup mode, the calibration factor of indoor bare mode CR-39 and the diffusion coefficient with transmission factor of sponge and filter paper.

Materials and methods

The chamber used in these measurements was built in the Environmental Pollution Laboratory, of College of education University of Basrah. It is consist of 50cm arc of cubic PVC chamber contains radioactive source ^{226}Ra (185kBq). After the completion of preparation the calibration radon chamber, it will be ready to measure the calibration factors for any dosimeters. According to criteria that, if you have instrument measured alpha particles concentration per unit volume and the equivalents track number, then the calibration factor is simply the average of dividing the track density to the equivalents concentration. In order to start measuring the radon concentration inside the chamber after inserting the radon source (^{226}Ra) and sealed all opening of the chamber by cold silicon, we switched on the radon monitor (Radon Scout).

Radon Scout instrument from SARAD (Germany), shown in Figure 1, focused on the detection of Radon (Rn-222) in the air. The chronological data sets will be available for transfer to PC using comfortable software for read out the radon concentration each hour. No mechanical part like a member pumps an external power supply is required. Therefore, the use and exposition at home or at workplace is possible without any disturbance. A total duration of measurement of up to four month with continuing data recording is possible.



Time: **5/8/2008 0:19** Radon: **191 Bq/m³ ±11%** **19.5°C** **51 %** **990mbar**

Device Number: **Radon-Scout / 97**
Data Records: **19**
Sample Period: **5/13/2008 4:19 - 5/16/2008 8:19**
Exposure Time: **76.0 hours**
Average: **231 Bq/m³ ±2.4%**
Exposure: **17579 Bqh/m³**
Start Test: **5/13/2008 4:19**
End Test: **5/16/2008 8:19**

Figure-1 Radon Scout enstrument From Sarad and the output data window.

The instrument saves the date of the whole experiment and could be transferred to a computer for analyzing. The background measurement was done by Radon Scout before starting any measurement.

A. *Calibration factor for LR-115 Type-II used in twin-cup dosimeter*

LR-115 type-II twin- cup dosimeter inserted into 5.5 cm x4.5 cm containers, which used in indoor measurements of radon concentrations, is shows in Figure 2. The chamber has cubic shape of length 50 cm and equipped with the necessary accessories [14]. The cups contained detectors were hung freely in the radon chamber for 27.4 days after equilibrium; the radon gas concentration inside the chamber at this time was 949Bq/m^3 measured by radon detector. The detectors were removed and etched with 2.5N NaOH at 60^o C for 90 minutes for LR-115. The tracks were counted for many field areas using 400X microscopes to determine the track density per cm^2.

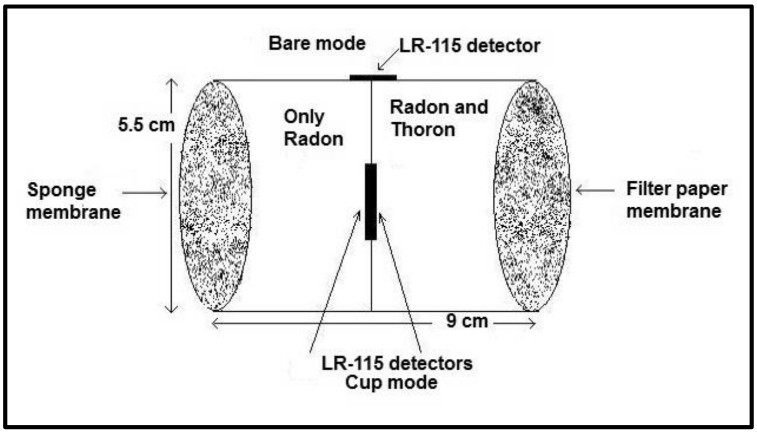


Figure-2: Twin LR-115 cup dosimeter.

B. *Calibration factor for CR-39 indoor in bare mode*

A group of CR-39 detectors each was fixed on cardboard slide and hanged freely in the radon chamber. Each CR-39 detectors were exposed to radon for a different exposing time (121, 191, 361 and 601 hours). Radon Scout monitor was recorded radon concentration each hour up to equilibrium state where the concentration is stable at its saturation. At the end of exposure, the CR-39 detectors were immediately removed and stored in shielded storage inside the chamber until the end of the experiment. The detectors were etched with 6.25N NaOH at 70^o C for 7 h. The tracks were counted for many field areas using 400X microscopes to determine the track density per cm^2.

C. *Diffusion coefficient of sponge and filter Paper*

The principle of the measurement is to observe the radon gas flow from a part of container with high concentration to through the medium to the second container with much lower radon concentration. The system is assumed to be in the steady state after a time much longer than the relaxation time [19]. We designed twin calibration containers from PVC, separated by a sheet of sponge or filter paper as shown Figure 3.These containers set inside the calibration radon chamber as well as radium source to generate the radon gas. In the case, where the transportation of gas is considered only in one direction, the production of radon inside the media can be neglected [20].

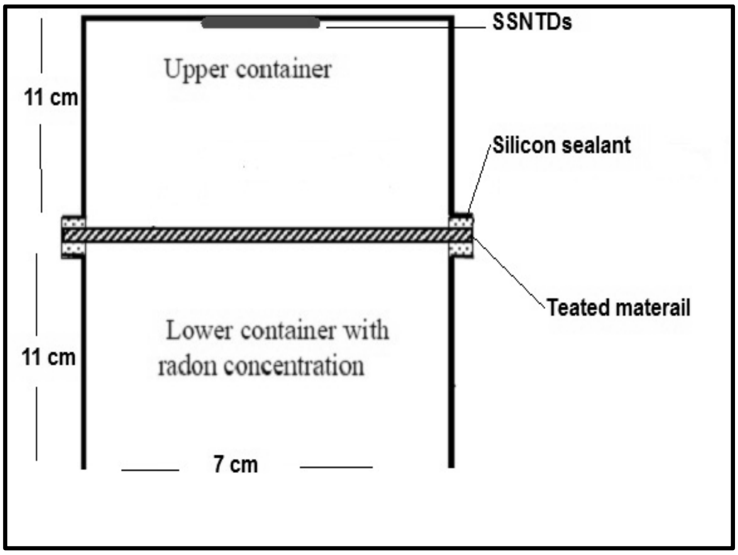


Figure- 3: Twin calibration containers PVC separated by a piece of sponge or filter paper

The small amount of water in the membrane can influence the diffusion and therefore the reaction (binding of water) inside the material should be stopped and equilibrium of humidity inside and outside had to be reached ***[20].*** Radon concentration of the lower containers was measured by the radon monitor who records radon concentrations each hour of equilibrium state, when the concentration is stable at its maximum. Radon concentration of upper containers was measured by CR-39 detector. Both containers were calibrated inthe Environment Pollution Laboratory, College of Education Pure Sciences, Basrah University [14].The measurement was made under normal laboratory conditions (temperature about 25° C and relative humidity about 37%). The detectors were etched with 6.25N NaOH at 70° C for 7 h. The tracks were counted for many field areas using 400X microscopes to determine the track density per cm^2, which can be used to determine the radon concentration of upper containers.

Results and discussions

A. Calibration factor for LR-115 indoor twin cup dosimeter

Table 1 shows the results of the laboratory experiment for the calibrations in different exposure modes. The results are in good agreementwith the cup mode for LR-115 type-II detectors [21, 22].

Table 1: The results of the laboratory experiment for the calibrations in Twin cup

Mode of exposures	*Exposure time (h)*	*Average radon concentration ($Bq.m^{-3}$)*	*Track density ($Tr.cm^{-2}$)*	*Calibration factor Track.cm^{-2}/Bq.m^{-3}.d*	*Results of Ref. [21]*	*Results of Ref. [22]*
R-115 Sponge cup mode	*657*	*948.69*	*515.58*	*0.020±0.005*	*0.016±0.002*	*0.020±0.004*
LR-115 Filter cup mode	*657*	*948.69*	*540.73*	*0.021±0.006*	*0.017±0.003*	*0.019±0.003*
LR-115 Bare mode	*657*	*948.69*	*754.51*	*0.029±0.008*	*0.018±0.002*	*0.020±0.002*

B. Calibration factor for CR-39 bare mode

Figure 4 shows the track density in ($Tr.cm^{-2}$) as a function of radon exposure dose in ($Bq.m^{-3}$. d). The best straight line was fitted and from the slope of this line, the calibration factor of the CR-39 polymeric detector using hybrid method is found. The calibration factor for CR-39 detector in the bare mode estimated to be $K= 0.384\pm0.102$ $Tr.cm^{-2}$/ $Bq.m^{-3}$.d.

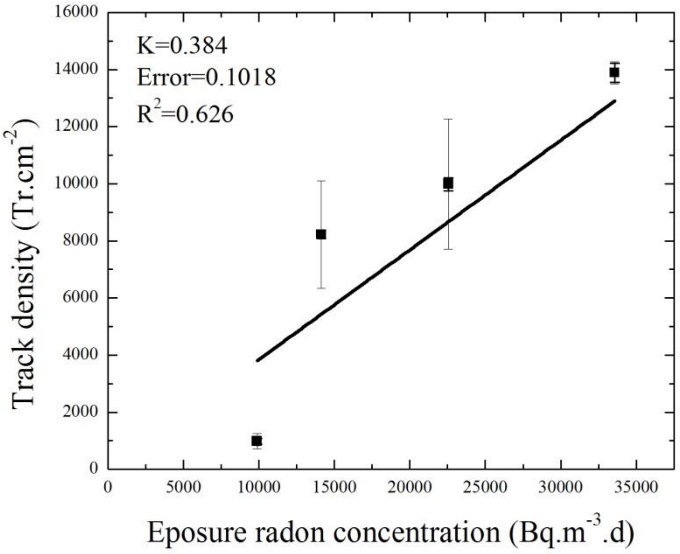


Figure - 4: Plots between track density in Tr.cm^{-2} and radon exposure in Bq.m^{-3}.d measured by CR-39 bare mode

From these two experiments, it is reasonable to mention that, the value of calibration factor in bare mode is larger than the cup mode for all types detectors because the radon concentration is large and the detector recorded large number of tracks [14]. Also, the value of calibration factor for CR-39 is larger than LR-115 type-II in all modes because, this may related to: CR-39 is sensitive to all alpha energies unlike LR-115 type-II detector which has energy window [23].

C. *Diffusion and transmission factors*

Radon transport in porous material is described by a general equation of continuity, which includes four basic processes: generation, decay, diffusion and convection. Under the supposition of the time – dependent one – dimensional differential equation (no convection) describing the radon activity concentration C_0 is given by Fick's second law [24]:

$$\frac{\partial C_0(z,t)}{\partial t} = D_e \frac{\partial^2 C_0(z,t)}{\partial z^2} - \lambda\, C_0(z,t) + P \qquad (1)$$

where$C_0(z,t)$ is the radon concentration within the pores (Bq/m^3),

$$D_e = \frac{D}{\varepsilon} \qquad (2)$$

$$P = \frac{f\,\lambda\, C_{Ra}\,\rho}{\varepsilon} \qquad (3)$$

where D is the bulk diffusion coefficient (m^2/h, gas flux expressed per unit area of material as a whole), D_e is the effective diffusion coefficient, ε is the porosity and λ is the radon decay constant, and P is the production rate of radon in the pore air (Bq/m^3.h), f is the emanation fraction, ρ is the bulk density (Kg/m^3) and C_{Ra} is the radium concentration (Bq/Kg). By using time – dependent one – dimensional differential equation (Fick's second law), Fick's first law and special boundary conditions one can calculate the radon diffusion coefficient and transmission factors respectively ***[25,26]***. We found simple relation to calculate the effective diffusion coefficient and transmission factor as the ratio between the concentrations inter cup and outside cup

$$D_e = \frac{\lambda\, d\, h}{\frac{C_1}{C_2} - 1} \qquad (4)$$

where lower container has high (h) and radon concentration C_1 and upper container has high (h) and radon concentration C_2 and the material has thickness d.The transmission outside the cup written as;

$$Transmission\ (\%) = \frac{\frac{l_2}{L}}{\frac{\lambda\, l_2 \delta}{D_e} + \coth\left(\frac{L}{l_2}\right)} \quad (5)$$

$$l_2 = \sqrt{\frac{D_{air}}{\lambda}} \quad (6)$$

wherel_2 is the diffusion length of radon in air (m). L is length of closed cylindrical chamber (dosimeter cup) and δ is thickness of porous filter.Table 2 shows the radon diffusion coefficients and transmission factors for filter paper and sponge.

Table 2: The values of diffusion coefficient and transmission factor for filter and sponge.

Tested material	*Thickness*	*Diffusion coefficient m^2/sec*	*Transmission factor %*	*Transmission factor%[27]*
Filter paper	*0.8 mm*	7×10^{-13}	*90.5*	-
Sponge	*5 mm*	4×10^{-9}	*89.5*	*90*

From the table one can see that, the diffusion coefficient for sponge greater than filter paper. This matter can be explained due to the thickness and the fact that the nature pores and network channels that gas run through on all sponges which makes the pathway of the radon gas inside the sponge zigzag and leads to reducethe concentration when it passed through it. Whatever, the case the diffusion coefficients for filter paper and sponge much less than for all building materials [20]. The results of transmission factors of radon for both filter paper and sponge are same and these results identify with other researches [27].

Conclusions

From the results of the present experiments, we have shown that, the hybrid radon detection systems combining passive LR115-II and electronic radon gas counting gives a good achievement in calibration factors, detector efficiency and diffusion factors measurements. The results of the present calibration experiment show the relationship between the track production rate and the radon exposure concentration in the exposure chamber is linear and hence; the calibration graphs can be extrapolated to other range of radon concentrations and give close agreement with other calibration experiments. The methodology, although not precise, is simple and the reported calibration factors can normally be used in many radon concentration ranges. The value of the calibration factors depend on the type of the SSNTD detector and the mode of experiment applied.

The transmission of sponge and the filter paper were 90%, means a small amount of gases prevented from passing through and this is within the experimental error.

References

[1] El-Din, N. W., El-Shershaby, Ahmed F and Abdel-Haleem, A. S. *"Measurement of radioactivity and radon exhalation rate in different kind of marbles and granites"* Applied Radiation and Isotopes,Vol.55, pp. 853-860. (2001).

[2] Saad, A. f., Talaat, T. M., Atwa, S. T., Espinosa, G and Fujii, M.*"determination of the uranium content ofEgyptian phosphate ores by passive and active detectors"*. Radiation Measurements, Vol.40 No 2, pp. 780-784. (2005).

[3] Shakinr, Khan M., Naqvi, A. H. and Azam, A., "*Study of indoor radon and its progeny levels in rural areas of North India using Lr-115 plastic track detector*", Radiation Measurements, Vol.43, pp. 385-388, (2008)

[4] Shweikani, R. and Raja, G., *"Radon exhalation from some finishing materials frequently used in Syria"*, Radiation measurements, Vol. 44, pp. 1019-1023, (2009).

[5] Kurnaz, A, Kucukomeroglu, B., Cevik, U. and Celebi, N., *"Radon level and indoor gamma doses in dwelling of Tranzon, Turkey*", Applied Radiation Isotopes, Vol.69,pp. 1554-1559,(2011).

[6] Saad, A. F., Abdallah, R. M. and Hussein, N. A., *"Radon exhalation from Libyan soil samples measured with SSNTD technique"*, Applied Radiation Isotopes, Vol. 72, pp. 163-168,(2013).

[7] Sahoo, B. K.,Sapra, B. K., Kanse, S. D., Gaware, J. J. and Mayya, Y. S., *"A new pin-hole discriminated* ^{222}*Rn/*^{220}*Rn passive measurement device with single entry face*", Radiation Measurements, Vol. 48, pp. 1-9,(2013).

[8]Srivastava, D. S.; Singh, P.; Rana, N. P. S.; Naqvi, A. H.; Azam, A.; Ramachandran, T. V., Subba Ramu, M. C.,"*Calibration factor for LR-115 type II track detectors for environmental radon measurements"*, Nuclear Geophysics, Vol. (9), No. 5, pp. 487-495, (1997).

[9] Eppen, K.P. and Mayya, Y. S." Calibration factors for LR-115 (type-II) based radon/thoron discriminatingdosimeter", Radiation Measurements, Vol. 38, pp. 5-17, (2004).

[10] Leung, S.Y.Y., Nikezic, D., Leung, J. K. C. and Yu, K. N."Derivation of V function for LR 155 SSNTD from its sensitivity to ^{220}Rn in a diffusion chamber", Applied Radiation and Isotopes, Vol. 65, pp. 313-317. (2007).

[11] Yu, K. N., Koo, V. S.Y. and Guan, Z. J.," A simple and versatile ^{222}Rn/^{220}Rn exposure chamber", NuclearInstrument and Methods in Physics Research A, Vol. 481, pp.749-755, (2008).

[12] Wanabongse, P., Sola, B., Jamsangtong, J. and Rattanabussayaporn, S. " Calibration of CR39 solid state nuclear track detector", Indian journal of Physics, Vol 83, No.6, pp. 833-837.(2009).

[13] Al-Nafiey, M. S., Jaafar, M. S., Bauk,Bin, S. and Salih, N. F."Design and Fabrication of new radon chamber for radon calibration factor of measurement", International Journal of Scientific and Engineering Research, Vol. 3 No 10, pp. 1-6, (2012).

[14] Abdul, R.H. Subber, Noori, H.N. Al-Hashmi, Ali, F. N.,Jabbar, H. J. , and Khodier,M. K.

"Construct as a simple Radon Chamber for Measurement of Radon Detectors Calibration Factors", Pelagai Research Library,Vol. 6 No.2, pp. 128-136,(2015).

[15] Jojo, P. j., Khan, A. J., Tyagi, R. K., Ramachandran, T. V., Subba, M C. and Prasad, R."Interlaboratory calibration of track-etch detector for the measurement of radon and radon daughter levels", Radiation Measurements, Vol 23 No.4, pp. 715-724,(1994).

[16] Srivastava, D. S., Sing, P., Rana, N. P. S., Naqvi, A. H., Azam, A., Ramachandran, T. V. and Subba, M. C.,Calibration factor for LR-115 Type- II track detector for environmental radon measurements, Nuclear Geophys.,Vol. 9 No.5, pp. 487-495,(1995).

[17] Gericke, C., Ghose, R., Jonsson, G., Freyer, K., Treutler, H. C. and Enge, W."The calibration of the solid state nuclear track detector LR-115 for radon measurements", Radiation Measurement, Vol. 31, pp. 363-366, (1999).

[18] Xu B., Burnet, W. C., Lane-Smith, D. and Yu, Z. "A Simple laboratory-based radon calibration system", J. RadioanalNucl. Chem., Vol. 283, pp. 457-463,(2010).

[19] Martin, J., Jiri, H. "Radon diffusion coefficient in radon-poor membranes determination and applicabilityfor the design of radon barriers", International Journal on Architectural Science, Vol.(1), No. 4,pp 149-155,(2000).

[20] Keller, G. and Hoffimann, B."The radon diffusion length as a criterion for the radon tightness", IRPA10 Conference Proceedings Hiroshima.(2000).

[21] Esaiselvan, K., Allen, G. R. "Assessment of radioactivity and estimation of effective radiation dose received by villagers residing at natural high background areas of coastal regions of tamilnadu", International Journal of Innovative Research, Engineering and Technology, Vol.2 No.6, pp.2243-2247 (2013).

[22] Ramachandan,T. V. L. A. Sathish, and Sundareshan,S. "Nationwide ^{222}Rn and ^{220}Rn Atlas for India: a review, Journal of Environmental Radioactivity"**,** Vol.102 No11, pp. 975–986,(2011).

[23] Barillon, R., and Chambaudet, A." Alpha- particle dosimety using solid state nuclear track detectors: Application to ^{222}Rn and its daughters", Journal of Radioanalytical and Nuclear Chemistry, Vol. 243, No. 3, pp. 607-620.(2000).

[24] Cosma, C., Dancea, F., Jurcut, T., Ristoiu D."Determination of ^{222}Rn emanation fraction and diffusion coefficient in concrete using accumulation chambers and the influence of humidity and radium distribution", Applied Radiation and Isotopes Vol. 54, pp. 467-473.(2001).

[25] Oufni, L."Determination of the radon diffusion coefficient and radon exhalation rate in Moroccan quaternary samples using the SSNTD technique", Journal of Radio analytical and NuclearChemistry, Vol. (256), No. 3, pp. 581-586.(2002).

[26] Masahiro, H., Shinji, T., Atsuyuki, S., Miroslaw, J., Tetsuo, I., Yoshinori, Y., Junya, Y. and Shigeo, U., "Experimental system to evaluate the effective diffusion coefficient of radon", Review of Scientific Instruments 80, 013501.(2009).

[27] Eappen, K.P. and Mayya, Y. S. "Calibration factors for LR –115 (Type-II) based radon thoron discriminating dosimeter", Radiation Meas., Vol. 38, pp. 5 –1 7,(2004).