**PAPER • OPEN ACCESS**

# Calibration of CR-39 for different heights of radon dosimeters and application of radon concentration in Mahajran River sediment in Basra Governorate, Iraq

To cite this article: Jabbar H Jebur *et al* 2019 *J. Phys.: Conf. Ser.* **1294** 022013

# Calibration of CR-39 for different heights of radon dosimeters and application of radon concentration in Mahajran River sediment in Basra Governorate, Iraq

**Jabbar H Jebur[1], Subber Abdul R H [2] and Wejood Tuama Saadon [3]**

[1]Physics Department, College of Education for Pure Sciences, University of Basrah, Iraq
[2]Al-Kunooze University College, Basrah, Iraq
[3]Technical Follow-up Officer/ oil Pipe line Company/ Ministry of oil/Iraq

**Email :** swmn1999@gmail.com

**Abstract.** Radon and its progenies are the main cause of lung cancer when they are trapped inside the lungs. Therefore, the radon activity concentration in air, water and soil samples should be measured, monitored and analysed. In this paper, river sediment samples collected from 30 different locations of Mahajran River, Basra, Iraq, were studied by using solid-state nuclear track detector type CR39. The track detector used for this purpose must be calibrated for concentrations of radon, Thoron and their daughters likely to be found in samples. The chamber used in the present calibration work had a volume of 125 L and contained a standard radon source ($^{226}$Ra) and radon distribution fan. Results illustrated the dependence of the CR-39 calibration factor on the dosimeter height. The calibration factor used in this application was $0.34\pm\mathbf{0.03}$Tr/cm$^2$·day / Bq·m$^{-3}$ for a height of 10 cm.

**Keywords:** Mahajran River, Radon in sediment, Calibration Factor CF, CR-39, Radon Chamber, RadonScout.

## 1. Introduction

For a healthy environment, routine measurements of radioactive radon gas concentration outdoors, indoors, water and soil must be carried out. Radon gas is a radioactive gas produced by the decay of $^{226}$Ra and $^{228}$Ra isotopes ($^{222}$Rn= half-life of 3.83 days from $^{226}$Ra and $^{220}$Rn = half-life of 56 s from $^{228}$Ra). This gas produces solid radioactive daughters $^{218}$Po and $^{214}$Po, which are hazardous due to their fast and high-energy alpha particle decay [1,2]. Different modes of measurements can be used to estimate the concentration and exhalation rate of this gas; some methods are active methods that use electronic devices, and others are passive methods that employ solid-state nuclear track detectors (SSNTDs); the latter are popular for their precision and simplicity [3–8]. However, the estimation of radon concentration and exhalation rate in an environment that uses passive methods (SSNDTs) requires a parameter that converts track density (in track/cm$^2$) to radon concentration (in Bq/m$^3$), called calibration factor of the detector / conversional factor / response factor / turned over sensitivity factor [9–11]. It converts the track density ( $\mathrm{Track.cm^{-2}}$) to exposure concentration (Bq·m$^{-3}$·day). This parameter can be determined using a standard radon source ($^{226}$Ra) and electronic instrument to measure the activity concentration in the space by the well-sealed radon chamber.Many types of multipurpose radon chambers have been designed [12–15]. These chambers have been used to determine the calibration factors of CR-39 or LR-115 detectors for alpha decays of $^{222}$Rn or $^{220}$Rn. The present work aimed to determine the calibration factors of the CR-39 detector for different heights of radon dosimeters using a hybrid between active and passive methods. One of the calibration factor values was utilised as an application to measure radon concentration emanating from river sediment.

## 2. Material and Methods

The Mahajran River is located in the southern part of Basra Governorate, Iraq (Figure 1), and it is close to a fertilizer plant on the bank of the Shatt al-Arab. Sediments from the river were obtained every 150 m of the river's length. Sediments contained a mixture of sand, clay, silt, large number of minerals and rocks mostly from the west of the factory. Wet samples were obtained from 1 m deep every 150 m of the river for analysis. Each sample was dried in an oven at 100 °C–110 °C for 24 h and sieved to remove stone, pebbles and other macro impurities.


**Figure 1**.Satellite map for Mahajran River

### 2.1. Experimental procedure

To measure the radon activity concentration in samples, the sealed can technique was performed in the laboratory [16–18]. About 200 g of dried sample was placed at the bottom of the can (7.0 cm × 10 cm), as shown in Figure 2. The dosimeters were stored (closed) for 4 weeks to reach secular equilibrium between radium and radon. After this period, CR-39 plastic detector (1.5 cm × 1.5 cm), which was previously fixed by adhesive tape to the inside surface of a second identical cover, was mounted quickly. The chamber was then closed, and the upper cover of the container was sealed using cold silicon. The detector was exposed to $^{222}$Rn for 90 days. After the exposure time, all detectors were removed carefully and then chemically etched using a solution of 6.25 N NaOH at 70 °C for 7 h. The detectors were washed continuously with distilled water. The tracks that emerged on the surface of the detector were counted using a microscope at 400×.

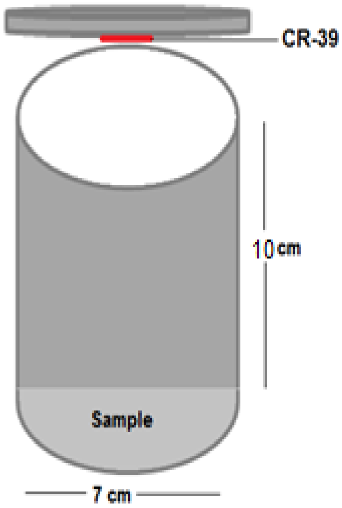


**Figure 2**.A schematic diagram of the dosimeter used in present work.

In this technique, the radon level of soil placed in an emanation container was monitored with a passive radon dosimeter by using the CR-39 SSNTD. The radon concentration that emanated from the sample inside the closed can was calculated using the following equation [19, 20]:

$$C_{Rn} = \frac{\rho}{TK} \qquad (1)$$

where$\rho$ is track density (Tr/cm$^2$),T is exposure time (day) and K is the calibration factor. The calibration coefficient is expressed as units (track/m$^2$)/(Bq·s/m$^3$)=m. In the literature, it is also given in (track/cm$^2$)/(Bq·h/m$^3$), (track/cm$^2$)/Bq·d/m$^3$ or Tr·cm$^{-2}$/day·Bq·m$^{-3}$ [21]. The value of K depends on the radius and effective height of the measuring can. At the equilibrium state, the surface exhalation rate from the sample inside the dosimeter is calculated by[22]

$$E_{ex} = \frac{A_{Rn}TV\lambda/S}{T+\lambda^{-1}\left(e^{-\lambda T}-1\right)} \qquad (2)$$

where $E_x$ is the area exhalation rate (in Bq m$^{-2}$·h$^{-1}$); A is the radon concentration measured by the CR39 detector (in unit Bq m$^{-3}$); $\lambda$ is the radon decay constant, which is equal to 0.181 day$^{-1}$; T is the exposure time; V is the volume of air space in the can; and S is the surface area of the sample.
The mass radon exhalation rate was calculated with the following equation [22]:

$$E_M = \frac{A_{Rn}TV\lambda/M}{T+\lambda^{-1}\left(e^{-\lambda T}-1\right)} \qquad (3)$$

where $E_M$ is expressed in Bq kg$^{-1}$h$^{-1}$, and M is the mass of the sample.
The effective radium content in the sample was calculated from [22]

$$A_{Ra} = \frac{\rho\, V}{KMT_{eff}} \qquad (4)$$

where$T_{eff} = T - \lambda^{-1}(1 - e^{-\lambda T})$

### 2.2. Calibration Chamber

In any physical measurement, the calibration factor must be determined for the same geometry conditions as the studied samples. The samples of interest mounted in the sealed cylindrical polyethylene can (diameter of 7 cm and height of 15 cm) were used.The chamber used in these measurements was built in the Environmental Pollution Laboratory, College of Education for Pure Science, University of Basra (Figure 3 and 4) [23]. It was constructed of 50 cm arc of cubic PVC chamber, which contained radioactive source $^{226}$Ra (185 kBq and half-life of 1600 years). After the radon chamber was completed, it was employed to measure the calibration factors for any dosimeters and any type of SSNTD. 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. To measure the radon concentration inside the chamber, a Radon Scout (SARAD Company), which can measure the radon concentration every hour and is supplied with dry batteries that can last for 3 months, was mounted inside the chamber. This instrument saved data during the entire experiment and could be transferred to a computer for analysis. Background measurements were conducted by the Radon Scout before starting any measurement and subtracted later. Different heights (5, 10, 15, 20, 25, 30, 35, 40 and 45 cm) of dosimeters were used to measure the calibration factor for the CR-39 detector as a function of dosimeter height. The detector was mounted inside the chamber as shown in Figure 4. A 1.5 cm × 1.5 cm detector was fixed on the top of the inner surface of the can using double adhesive tape such that its sensitive surface faced the radon source. The Radon Scout monitored the recorded radon concentration every hour up to the equilibrium state, in which the integrated concentration was stable at its maximum (11522± 576Bq/m$^3$). Each detector was exposed to a constant radon concentration for 27.125±0.120 days. At the end of the exposure time, the CR-39 detector was immediately removed from the cans and stored inside the lead cylinder in the chamber until the end of the experiment. The detectors were etched with 6.25 N NaOH at 70 °C for 7 h. The tracks were counted for many fields (20 fields) using a 400× microscope to determine the track density per square centimetre.

Figure (3) Radon chamber

Figure (4) group of dosimeters

## 3. Results of CR-39 Calibration measurement

Table 1 shows the rack density after subtracting the background, as well as average calibration factor calculated using Equation (1). The results of the calibration factor may be used for any dosimeter height up to 45 cm.

**Table 1** The values of the calibration factors for different height dosimeters

| No. | h (cm) | Average track density ($Tr/cm^2$) | K $Tr.cm^{-2}/day.Bq.m^{-3}$ |
|---|---|---|---|
| 1 | 5 | 112500∓8438 | 0.360∓0.032 |
| 2 | 10 | 105000∓7875 | 0.336∓0.030 |
| 3 | 15 | 101875∓7641 | 0.326∓0.029 |
| 4 | 20 | 97500∓7313 | 0.312∓0.028 |
| 5 | 25 | 94375∓7078 | 0.302∓0.027 |
| 6 | 30 | 85000∓6375 | 0.272∓0.025 |
| 7 | 35 | 81875∓6141 | 0.262∓0.024 |
| 8 | 40 | 78750∓5906 | 0.252∓0.023 |
| 9 | 45 | 75625∓ 5906 | 0.242∓0.021 |

This table demonstrates that the calibration factors were inversely proportional to the height of the dosimeter. This finding was normal because radon gas is a dense gas, and its concentration decreased with the height of dosimeter at constant diameter.Figure 5 represents values of calibration factors with height dosimeter h. The best straight line and its linear equation were found. This experimental relationship was used to calculate calibration factor as a function for height dosimeter at constant radius (r = 3.5 cm).

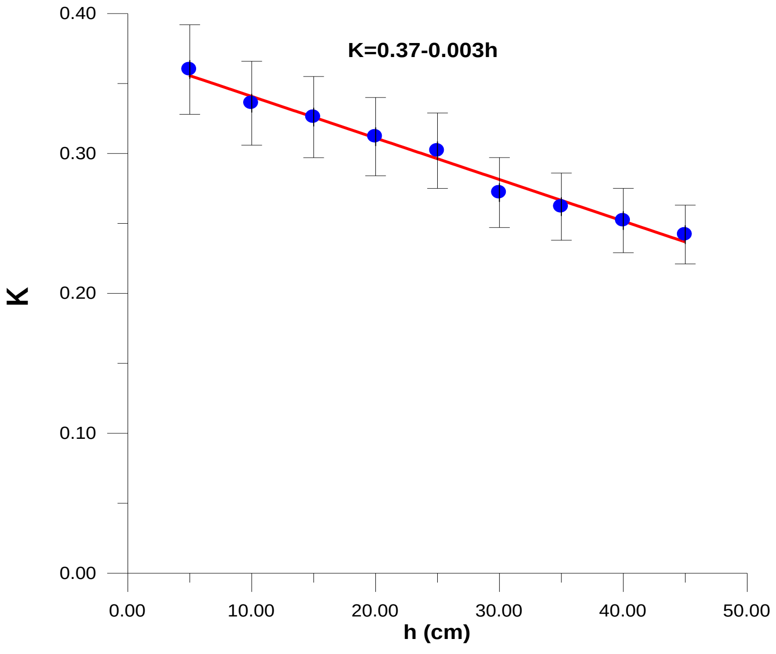


**Figure (5)** The values of calibration factors in units $Tr.cm^{-2}/day.Bq.m^{3}$ withheight dosimeter h in cm.

## 4. Results of Application

Equation (1) has been used to calculate radon concentrationin sediment samples collected from Mahajran. River.The calibration factor of CR-39 detector used was 0.34 $Tr.cm^{-2}/day.Bq.m^{-3}$ with uncertainty of about ∓9%which calculated from the relation of the best straight line of experimental data in figure 5 with h=10 cm for effective height.The results of radon concentration level, surface radon exhalation rate, mass exhalation rate and effective $^{226}$Ra concentrations in sediment samplesare listed in table 2.

**Table2:**The radon levels, area and mass exhalation rate and effective radium content in sediment samples of Mahajran River.

| Sample No | Radon Con. in Bq/m$^3$ | Area Exhalation Rate Bq/m$^2$. h | Mass Exhalation Bq/kg. h | Effective Ra in Bq/kg |
|---|---|---|---|---|
| 1 | 274.45 | 0.220 | 0.00924 | 0.562 |
| 2 | 185.02 | 0.148 | 0.00286 | 0.380 |
| 3 | 202.69 | 0.163 | 0.00313 | 0.415 |
| 4 | 320.19 | 0.257 | 0.00495 | 0.655 |
| 5 | 187.12 | 0.150 | 0.00289 | 0.383 |
| 6 | 205.83 | 0.161 | 0.00318 | 0.421 |
| 7 | 334.74 | 0.269 | 0.00517 | 0.685 |
| 8 | 259.89 | 0.209 | 0.00402 | 0.532 |
| 9 | 287.96 | 0.231 | 0.00445 | 0.589 |
| 10 | 353.45 | 0.284 | 0.00547 | 0.724 |
| 11 | 391.92 | 0.315 | 0.00606 | 0.802 |
| 12 | 217.27 | 0.174 | 0.00336 | 0.445 |
| 13 | 239.10 | 0.192 | 0.00370 | 0.489 |
| 14 | 298.36 | 0.240 | 0.00462 | 0.611 |
| 15 | 374.25 | 0.301 | 0.00579 | 0.766 |
| 16 | 267.17 | 0.215 | 0.00413 | 0.547 |
| 17 | 386.72 | 0.311 | 0.00598 | 0.792 |
| 18 | 168.41 | 0.135 | 0.00266 | 0.345 |
| 19 | 156.97 | 0.126 | 0.00243 | 0.321 |
| 20 | 176.72 | 0.142 | 0.00273 | 0.362 |
| 21 | 251.58 | 0.202 | 0.00389 | 0.515 |
| 22 | 252.27 | 0.203 | 0.00390 | 0.516 |
| 23 | 171.53 | 0.138 | 0.00265 | 0.351 |
| 24 | 316.03 | 0.254 | 0.00489 | 0.647 |
| 25 | 302.51 | 0.243 | 0.00468 | 0.619 |
| 26 | 206.87 | 0.166 | 0.00320 | 0.423 |
| 27 | 323.31 | 0.260 | 0.00500 | 0.662 |
| 28 | 281.72 | 0.226 | 0.00436 | 0.577 |
| 29 | 326.43 | 0.262 | 0.00505 | 0.668 |
| 30 | 364.89 | 0.293 | 0.00565 | 0.747 |
| Av. | 269.51 | 0.216 | 0.00434 | 0.552 |
| Max. | 391.92 | 0.315 | 0.00924 | 0.802 |
| Min | 156.97 | 0.126 | 0.00243 | 0.321 |

The radon concentration varies from 156.97 Bq/m$^3$ to 391.92Bq/m$^3$with average value 269.51 Bq/m$^3$ and corresponding values of area exhalation rate from 0.126 Bq/m$^2$.h to 0.315 Bq/m$^2$.h and average value 0.216 Bq/m$^2$.h. These results were found to be consistent with data obtained by other investigators.The mass exhalation rate in sediment samples under investigation ranged from 0.00243 Bq.kg$^{-1}$.h$^{-1}$ to 0.00924 Bq. kg$^{-1}$h$^{-1}$, with arithmetic average value of 0.00434 Bq. kg$^{-1}$ h$^{-1}$. The effective radium responsible for radon emanation in the water ranges from 0.321 Bq kg$^{-1}$ to 0.802 Bq kg$^{-1}$ with average value of 0.552 Bq kg$^{-1}$. All data are within the range ofUNSCEAR and ICRP [1,2] for soil.

## 5. Conclusion

The calibration system for devices used to measure radon flux density from soil or sediment was established with accuracy less than 10%. The parameter that influenced the calibration factor most was the effective height of the accumulation can. These measurements were performed using a new multipurpose, calibration chamber, which was built to enable the SSNTD to be calibrated for radon concentration and exhalation rate measurements. The main purpose of this work was the direct application of calibration factor to determine radon activity concentration in river sediment. The sealed can technique is a convenient useful tool to determine the radon exhalation rates and effective radium concentration in samples of river sediments. The results obtained in this work were consistent with the reported data for similar cases.

## 6. References

[1 ] UNSCEAR, 2006 United Nations Scientific Committee on the Effects of Atomic Radiation, Report of UNSCEAR to the General Assembly, United Nations, New York, USA.,111–125.
[2 ] International Commission on Radiological Protection Statement on RadonICRP Ref 00/902/09, (2009).
[3 ] Saad A. F., Abdallah R. M. and Hussein N. A., 2013, Radon exhalation from Libyan soil samples measured with the SSNTD technique., Applied Radiation and Isotopes, 72, 163-168
[4 ] Alzoyubi F.Y., Al-Azzam K. M., Alqadi M. K., Al-Khateeb H. m., Ababneh Z. Q. and Ababneh A. M., 2013, Radon concentration level in the historical city of Jerash Jordan, Radiation measurements, 49, 35-38.
[5 ] Al-Jarallah M. I, Abu-Jarad F. and Rehman F., 2001, Determination of radon exhalation rates from tiles using active and passive technique. Radiation Measurements, 34, 491-495.
[6 ] Saad A. F., 2008, Radium activity and radon exhalation rates from phosphate ores using CR-39 on-line with and electronic radon gas analyzer "AlphaGuard"., Radiation measurements, 43, S463-S466.
[7 ] Ryzhakova N. K., 2014, A new method for estimation the coefficients of diffusion and emanation of radon in the soil., Journal of Environmental Radioactivity, 135, 63-66
[8 ] Halim Buyukuslu, F. BanuOzdemir, Tuba OzdemirOge and HalilGokce, 2018, Indoor and tap water radon (222Rn) concentration measurements at GiresunUnivsersoty campus areas, Applied Radiation and Isotopes, 139, 285-291.
[9 ] Khan A.J., Varshney A. K., Parasad R., Tyagi R. K. and Ramachandran T. V., 1990, Calibration of CR-39 Plastic Track Detector For the Measuremnt of Radon and its Daughters in Dwelling, Nucl. Tracks Radiat. Meas., V17,No. 4, 497-502.
[10 ] Al-Nafiey M. S., Jaafar M. S., Bauk Bin Saber and Salih N. F., 2012, Design and Fabrication of new radon chamber for radon calibration factor of measurement., International Journal of Scientific and Engineering Research, 3(10), 1-6
[11 ] Wanabongse P., Sola B., Jamsangtong J. and Rattanabuss S, 2009, Calibration of CR-39 solid state nuclear track detector. Indian journal of Physics, 83(6), 833-837.
[12 ] Leung S.Y.Y., Nikezic D., Leung J. K. C. and Yu K. N., 2007, Derivation of V function for LR 155 SSNTD from its sensitivity to $^{220}$Rn in a diffusion chamber, Applied Radiation and Isotopes, 65, 313-317.
[13 ] Yu K. N., Koo V. S.Y. and Guan Z. J.,2002, A simple and versatile $^{222/220}$Rn exposure chamber., Nuclear Instrument and Methods in Physics Research A, 481, 749-755

[14 ] Zhang X, Zhang Ye, Liu Y and Tang B., Evaluation of the uniformity of concentration of radon in Radon chamber, 2016, Applied Radiation and Isotopes, 110, 183-188.

[15 ] Onishchenko A., Zhukovsky M. and Bastrikov V., 2015, Calibration system for measuring the radon flux density, 2015, Radiation Protection Dosimetry, 164, 582-586.

[16 ] Jaber M. Q., Abdul. R. H. SubberandNoori H.N. Al-Hashmi, 2015. Natural radioactivity in marine sediment of Khor- Abdulla Northern west of the Arabian Gulf, Journal of Advances in Physics, 9(15),2340-2347

[17 ] Mayya Y.S. and Sahoo BK, 2016, A note on an erroneous formula in use for estimating radon exhalation rates from samples using sealed can technique, Applies Radiation and Isotopes 111, 8-9

[18 ] Subber A.R.H, Saadon W. T. and Hussain A. H., 2017, Measurement of radium concentration and Radon Exhalation Rates of Soil samples collected from selected area of Basra governorate, Iraq using plastic track detectors, J. Rad. Nucl. Appl. 2, No 1, 11-15.

[19 ] Alzoubif, Y., K.M. Al-Azzam, M.K. Alqadi, HM Al-Khateeb, ZQ Ababneh and A.M. Ababneh, 2013. Radon concentration level in the historical city of Jarash, Jordon. Radiation Measurements, 49,35-38.

[20 ] Sharma, D.K., A. Kumar, M. Kumar and S. Singh, 2003. Study of uranium, radium and radon exhalation rate in soil samples from some areas of Kangra district. Radiation Measurements, 36, 363-366.

[21 ] Stajic J.M, Milenkovic B and Nikezic D., 2018, Study of CR-39 and Makrofol efficiency for radon measurement, Radiation Measurement 117,19-23.

[22 ] Saad A.F. abdalla R.M. and Hussein N.A., 2013, Radon Exhalation from Libyan Soil Samples Measured with the SSNTD technique,Applied Radiation and Isotopes,72, 163–168.

[23 ] Subber, Abdul R.H. ,Noori H.N. Al-Hashimi, Ali Farhan Nader,Jabbar H. Jebur and M. K. Khodier, 2015, Construct as a simple Radon Chamber for Measurement of Radon Detectors Calibration Factors, Pelagia research library, advanced applied science research, 6(2),128-131.