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ARTICLE

# Radon Gas Detection of Soil Samples in Primary Schools at Najaf City, Iraq

**Rukia J. Dosh**[a], **Ali K. Hasan**[b] and **Ali A. Abojassim**[a]

[a] *Department of Physics, Faculty of Science, University of Kufa, Al-Najaf, Iraq.*

[b] *Department of Physics, Faculty of Education for Girls, University of Kufa, Al-Najaf, Iraq.*

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**Abstract:** The radon concentration, specific activity of $^{226}Ra$ ($C_{Ra}$), and $^{238}U$ concentrations ($C_U$) in soil samples from 100 primary schools of Al-Najaf province, Iraq, were measured to determine the safety of students and staff using the CR-39 nuclear track detector based on the sealed can technique. The mean values of $^{222}Rn$ concentration in the air space of the container (C) and the soil sample ($C_{Rn}$) were 23.53±1.149Bq/m3 and 960.38±47 Bq/m3, respectively. The mean values of $C_{Ra}$ and $C_U$ were 0.035±0.002 Bq/kg and 0.043±0.002 ppm, respectively. The $^{222}Rn$,$^{226}Ra$, and $^{238}U$ concentrations were lower than the worldwide level. Radiological parameters such as annual effective dose (AED) and radon exhalation rate per unit mass ($E_M$) and per unit surface ($E_S$) also were determined. The results indicate normal levels for these parameters, except for higher values of AED in some primary schools, according to UNSCEAR data.

**Keywords:** Radon, CR-39 detector, Soil of primary schools, Al-Najaf province.

## 1. Introduction

Radon is a radioactive, colorless, odorless, and tasteless noble gas that naturally occurs as an indirect decay product of uranium or thorium in the soil. It was first discovered by F.E. Dorn in 1900. Its most widespread and stable isotope, $^{222}Rn$, has a half-life of approximately 3.8 days and contains 99 percent of radon. Unlike radon, a noble gas, uranium and all of its daughters (up to lead) are solid elements. The short-lived radionuclides $^{218}Po$, $^{214}Pb$, $^{214}Bi$, and $^{214}Po$, produced as $^{222}Rn$ decays, are called radon daughters or progeny. Eventually, $^{206}Pb$ (stable lead) is produced. On average, 33 Bq/kg$^3$ of natural uranium (mainly $^{238}U$) may be detected throughout the Earth's crust, and consequently, in major earthen building materials. The gas dissipates fast in open areas; however, it can accumulate inside buildings, particularly in regions where the underlying ground is permeable and has a higher-than-average uranium concentration. Radon is present in all rocks and soils, both outdoors and indoors. Since outdoor air is constantly mixed and diluted, radon and its daughters rarely accumulate to dangerous levels. On the other hand, indoors, where ventilation may be limited, radon and its daughters can accumulate, reaching levels many orders of magnitude higher than those seen outdoors. Because radon's decay products can stick to ambient aerosols, inhaling them can cause the particles to be trapped in the lungs, delivering a dose to the lung's lining via alpha particle emission. As a result, instead of the radon progenitor, it is the radon progeny that poses the greatest health risk. The majority of radon exposure occurs indoors due to the high

**Corresponding Author:** Ali Abid Abojassim **Email**: ali.alhameedawi@uokufa.edu.iq

percentage of time people spend indoors and the elevated indoor radon concentrations compared to outdoor concentrations. Radon and its daughters are the primary sources of natural radiation exposure for the population, and many lung cancer cases have been documented as a result [2, 3]. The primary radiological exposure that humans experience internally comes from $^{222}$Rn. Geological and geophysical characteristics, as well as atmospheric factors like barometric pressure and rain, significantly impact the radon concentration range in the air. Radon can leak into the environment through rock fissures and soil pores close to the earth [4, 5].

Radon enters buildings through various channels, including soil gas, which infiltrates through tiny pores in the floor, cavities in interior walls, structural connections, gaps in walls, communication lines, building materials, and drinking water [1]. According to studies of radon's behavior in the geological environment, there is a clear relationship between indoor radon rates and soil gas concentration [2]. Therefore, testing for radon levels in as many schools and homes as feasible is one of the most efficient and effective strategies to lessen the risks to students in schools and other facilities [4]. Radon exposure in schools could have a significant public health effect. The chance of developing lung cancer in children exposed to radon could be as much as three times higher than in adults exposed to similar levels of radon. This is because children's lungs are not the same shape as those of adults, and children breathe more quickly than adults. Children generally spend more time indoors and are more vulnerable to environmental hazards. On average, Iraqi children spend 5 hours in school buildings daily, five days a week. Schools are also workplaces for teachers, administrators, and service staff, who may spend even more time in school buildings than students [6].

In order to determine long-term mean radon concentrations that can be used as the baseline data, passive measuring techniques are required. These techniques have been demonstrated to be effective and suitable for identifying radon and its daughters in soil samples [7-9]. This research aimed to establish a baseline for the Al-Najaf province by measuring the alpha emitters $^{222}$Rn, $^{226}$Ra, and $^{238}$U in soil samples taken from elementary schools. Values of radiological hazard indices like AED, $E_M$, and $E_S$ were also investigated.

## 2. The Study Area

The studied area of Al Najaf (Fig. 1) is located in southwestern Iraq, about 160 km southwest of Baghdad. It is situated at the intersection of longitude 44019E and latitude 31059N with an elevation of 70 meters above sea level [3].

One hundred primary public schools within Najaf city were chosen to study the concentrations of $^{222}$Rn, $^{226}$Ra, and $^{238}$U in the soil of these schools. The locations of these schools were identified using a GPS, as detailed in Table 1, and plotted using a GIS approach (ArcGIS 10.7.1.), as depicted in Fig. 1. Table 1 displays the chosen schools' names, locations, codes, types, dates of establishment, and coordinates.

TABLE 1. Information on schools included in the study.

| No. | Name | Location | Code | Type | Date | longitude | latitude |
|---|---|---|---|---|---|---|---|
| 1 | Alghaffari | Aljodaydat-2 | p1 | boys | 1919 | 436150.9 | 3539909 |
| 2 | Altahdhib | Aljodaydat-4 | p2 | boys | 1952 | 435944.2 | 3539177 |
| 3 | Malik Aliashtir | Aljodaydat-4 | p3 | boys | 1954 | 436064.3 | 3539492 |
| 4 | Halif Alquran | Al.Mothana | p4 | boys | 1958 | 438415.8 | 3540403 |
| 5 | Aishab Alkasa | Aljodaydat-3 | p5 | boys | 1959 | 436456.2 | 3539630 |
| 6 | Alhaidariya | Aljodaydat-1 | p6 | boys | 1933 | 436900.3 | 3540156 |
| 7 | Altaysir | Al.Karama | p7 | boys | 1964 | 438040.7 | 3542154 |
| 8 | Aleasifa | Al.Askan | p8 | boys | 1964 | 438584.1 | 3541338 |
| 9 | Dabel Al Khuzaie | Al.Moalmen | p9 | boys | 1968 | 437753.4 | 3539855 |
| 10 | Damascus Al'asasia | Alhussein | p10 | boys | 1973 | 436954.3 | 3541674 |
| 11 | Alsaadiq | Aljodaydat-3 | p11 | boys | 1953 | 437108.5 | 3539453 |
| 12 | Baghdad Al'asasia | Imam Mahdi | p12 | boys | 1964 | 437675.5 | 3539487 |
| 13 | Alghari | Al.Ansar | p13 | boys | 1964 | 438410 | 3538993 |
| 14 | Alamam Alhadi Al'asasia | Al.Ameer | p14 | boys | 1968 | 437237.6 | 3541669 |
| 15 | Eidun | Al.Shorta | p15 | boys | 1973 | 438586.6 | 3539133 |
| 16 | Mustafa Jawad | Al.Karama | p16 | boys | 1980 | 438162.7 | 3542366 |

| No. | Name | Location | Code | Type | Date | longitude | latitude |
|---|---|---|---|---|---|---|---|
| 17 | Alwathbi | Al.Ansar | p17 | boys | 1980 | 437318.7 | 3539070 |
| 18 | Sharif Al-Razi | Al.Zahraa | p18 | boys | 1980 | 438536.5 | 3540399 |
| 19 | Alshaeb | Aloroba | p19 | boys | 1982 | 437260.1 | 3545330 |
| 20 | Al-Safi Najafi | Alhawraa | p20 | boys | 1984 | 437418.1 | 3540301 |
| 21 | Badr Al-Kubra | AL gari | p21 | boys | 1984 | 436555.7 | 3542982 |
| 22 | Umm Qasr | Aloroba | p22 | girls | 1985 | 437645 | 3545648 |
| 23 | Alzainabiya | Aljodaydat-4 | p23 | girls | 1937 | 436100.7 | 3539435 |
| 24 | Sikina | Old City (AlBuraq) | p24 | girls | 1958 | 435403.2 | 3540360 |
| 25 | Ramallah | Old City (AlHoiesh) | p25 | girls | 1958 | 435289.5 | 3539809 |
| 26 | Alfadila | Alsaad | p26 | girls | 1955 | 437282.4 | 3540847 |
| 27 | Alsanabil | Al.Karama | p27 | girls | 1963 | 437555.3 | 3542139 |
| 28 | Fath | Alhussein | p28 | girls | 1968 | 437122.1 | 3541664 |
| 29 | Aleafa | Aljodaydat-4 | p29 | girls | 1963 | 436205.9 | 3539477 |
| 30 | Bilqis Al'asasia | Alhanana | p30 | girls | 1980 | 437418.1 | 3540301 |
| 31 | Al-Faraged | Al.Askan | p31 | girls | 1964 | 438584.1 | 3541338 |
| 32 | Almaqasid | Al.Moalmen | p32 | girls | 1964 | 437533.9 | 3539752 |
| 33 | Dijula | Aljodaydat-4 | p33 | girls | 1964 | 436003.5 | 3539253 |
| 34 | Mustafa Gamal El Din | Algahdeer | p34 | girls | 1968 | 438195.4 | 3542141 |
| 35 | Alanisaf | Al.Mothana | p35 | girls | 1973 | 438062.6 | 3540571 |
| 36 | Birdaa | Aljodaydat-2 | p36 | girls | 1953 | 435724.3 | 3539683 |
| 37 | Al-Bariq | Al.Moalmen | p37 | girls | 1979 | 437773.1 | 3539563 |
| 38 | Alamiani | Al.Ansar | p38 | girls | 1975 | 438284.5 | 3539077 |
| 39 | Nahj Al-Balaghah | Al.Ameer | p39 | girls | 1976 | 439542.8 | 3541498 |
| 40 | Alshiyma | Alshueara | p40 | girls | 1982 | 436966.2 | 3542333 |
| 41 | Alrisala | Al.Zahraa | p41 | girls | 1980 | 440067.1 | 3540535 |
| 42 | Alturath Alearabiu | Aljodaydat-3 | p42 | girls | 1981 | 437178.2 | 3539517 |
| 43 | Tabuk | AL gari | p43 | girls | 1981 | 436376.5 | 3542842 |
| 44 | Almakasib | Alhawraa | p44 | girls | 1980 | 439420.7 | 3539935 |
| 45 | Safin | Aladala | p45 | boys | 1984 | 439918 | 3542398 |
| 46 | Altadhia | Alwafaa (Alhindiya homes) | p46 | girls | 1986 | 438173.5 | 3546738 |
| 47 | Habib Bin Mazahir Al Asadi | Al.Askary | p47 | boys | 1986 | 437051.9 | 3548134 |
| 48 | Fataa Alaslam | Alwafaa (Alhindiya homes) | p48 | boys | 1986 | 437569 | 3546526 |
| 49 | Almasoudi | Alnasor | p49 | boys | 1988 | 434719.8 | 3544694 |
| 50 | Haifa | Aljameea | p50 | boys | 1988 | 436583.3 | 3546154 |
| 51 | Alhuru Alriyahiu | Almakrama | p51 | boys | 1988 | 436527.9 | 3547370 |
| 52 | Alyaequbi | Almilad | p52 | girls | 2001 | 435123.5 | 3546295 |
| 53 | Alainsar | Al.Ansar | p53 | boys | 1989 | 439450 | 3539128 |
| 54 | Almujd | Alishtiraki | p54 | girls | 1989 | 438880.2 | 3540828 |
| 55 | Alsahl Aliakhdaru | Alnasor | p55 | boys | 1989 | 434740.7 | 3545084 |
| 56 | Altabirsiu | Alqadisiya | p56 | girls | 1998 | 440709.1 | 3540836 |
| 57 | Alabirar | Alresalah | p57 | boys | 1989 | 436215.2 | 3545075 |
| 58 | Almuhajirin | Al.Ameer | p58 | girls | 1989 | 440263.9 | 3541439 |
| 59 | Alrahma | Aloroba | p59 | boys | 1989 | 436926.1 | 3546038 |
| 60 | 6 Kanun | Al.Askary | p60 | girls | 1990 | 437684.3 | 3547671 |
| 61 | Albayeat Alkubraa | Almakrama | p61 | girls | 1990 | 436707.1 | 3547077 |
| 62 | Sawr | Technical Institute | p62 | mixed | 1992 | 439985 | 3538170 |
| 63 | Albaraq | Al.Askary | p63 | girls | 1989 | 437014.8 | 3548494 |
| 64 | Alraazi | Alresalah | p64 | girls | 1994 | 436215.2 | 3545078 |
| 65 | Aliraq Alhuru | Al.Askary | p65 | boys | 1988 | 437727.2 | 3547168 |
| 66 | Saeed Bin Jubair | Alqadisiya | p66 | boys | 1988 | 440751 | 3540817 |
| 67 | Aldhaariat | New Almilad | p67 | girls | 2012 | 434860.7 | 3545810 |
| 68 | Alrabab | Alhussein | p68 | girls | 1998 | 436951.7 | 3541683 |
| 69 | Altawhid | Aljamea | p69 | boys | 1999 | 438828.5 | 3544025 |
| 70 | Ibrahim Al-Khalil | Aljamea | p70 | boys | 2000 | 439024.4 | 3544753 |
| 71 | Aalhaqu Almubin | Aloroba | p71 | girls | 2000 | 437260.1 | 3545330 |
| 72 | Alamam Alrida | Aljamea | p72 | girls | 2001 | 439249 | 3544157 |
| 73 | Alrafah | Aljamea | p73 | girls | 2001 | 439075.4 | 3544962 |
| 74 | Ali Al-Akbar | Aladala | p74 | girls | 2002 | 439427.9 | 3542919 |
| 75 | Aliaskandaria | Aljodaydat-4 | p75 | girls | 2004 | 436211 | 3538606 |

| No. | Name | Location | Code | Type | Date | longitude | latitude |
|---|---|---|---|---|---|---|---|
| 76 | Aljamie | Campus | p76 | mixed | 2004 | 437436.7 | 3548248 |
| 77 | Alshahid Mahdi Alhakim | Alsalam | p77 | girls | 2005 | 437404.1 | 3544440 |
| 78 | Albalad Al'amin | Alforat | p78 | girls | 2006 | 438923.4 | 3542786 |
| 79 | Khayr Albariya | Alsalam | p79 | boys | 2007 | 437920.6 | 3543540 |
| 80 | Alduea' Almustajab | Alsalam | p80 | girls | 2007 | 437920.6 | 3543539 |
| 81 | Eabuwd Ghafla | Abotalib | p81 | boys | 2007 | 435028.7 | 3543777 |
| 82 | Eadnan Zuin | Alkudos | p82 | boys | 2007 | 436911.5 | 3538568 |
| 83 | Aliaetimad | Abotalib | p83 | girls | 2007 | 435028.7 | 3543777 |
| 84 | Altaqwaa | AL gari | p84 | boys | 2009 | 436376.5 | 3542842 |
| 85 | Albayinat | AL gari | p85 | girls | 2009 | 436376.5 | 3542842 |
| 86 | Almawlaa Almuqadas | Alrahma | p86 | boys | 2010 | 435429.1 | 3542789 |
| 87 | Alsaafaat | Alrahma | p87 | girls | 2010 | 435429.1 | 3542789 |
| 88 | Abi Talib | Alforat | p88 | boys | 2010 | 439004.8 | 3542798 |
| 89 | Mohammed Jawad Mughniyeh | Alwafaa | p89 | boys | 2011 | 437972.2 | 3545979 |
| 90 | Sayf Alhaqi | Alrahma | p90 | boys | 2011 | 435429.1 | 3542789 |
| 91 | Alrusul | Alrahma | p91 | girls | 2011 | 435429.1 | 3542789 |
| 92 | Altasnim | Alnidaa | p92 | boys | 2013 | 434270.2 | 3548592 |
| 93 | Alsalam | majmae Alsalam | p93 | boys | 2013 | 436949.2 | 3544255 |
| 94 | Almathir | Alnidaa | p94 | girls | 2014 | 435106.2 | 3549344 |
| 95 | Jarf Alnasr | Alsalam | p95 | girls | 2014 | 436969.2 | 3544094 |
| 96 | Alamam Zayn Aleabidin | Alwafaa | p96 | girls | 2002 | 435412.3 | 3550484 |
| 97 | Alnasamat | New Almilad | p97 | girls | 2015 | 435005.5 | 3547121 |
| 98 | Alshahid Karim Alkhaqani | Alwafaa | p98 | boys | 2018 | 438734.5 | 3546279 |
| 99 | Aleawali | Algahdeer village | p99 | boys | 2018 | 437154.1 | 3549829 |
| 100 | Eata' Alnajaf | Algahdeer village | p100 | boys | 2018 | 436722.2 | 3550365 |

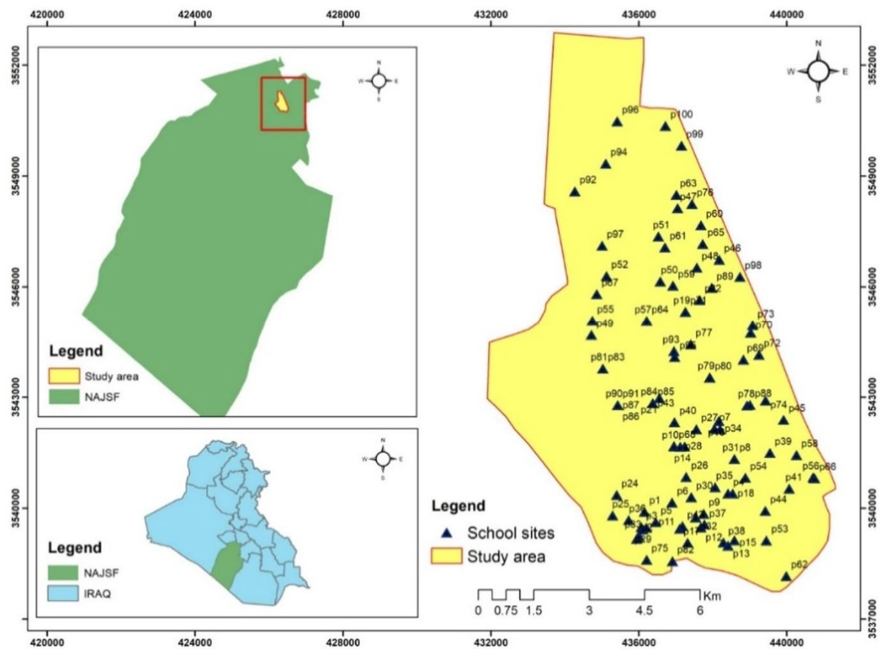

FIG. 1. A map of the field of study.

## 3. Materials and Methods

A total of 100 soil samples were collected at a depth of 15 cm from primary schools in Al Najaf city. Each sample was assigned a special code (refer to Table 1) and then sent to the laboratory at the Faculty of Science, University of Kufa. Each soil sample was dried inside an electrical furnace set to 105ºC for about 2-3 hours until all moisture was removed. Then the samples were crushed using a mill and passed through a 2 mm sieve. After this process, the samples were placed in cylindrical plastic containers with screw caps to provide a tight seal and prevent the release of radon gases.

To attain secular equilibrium, all samples were stored for at least one month. [4]. Following the sealed cup procedure, 70 g of the dried materials was placed at the bottom of a cylinder measuring 7 cm in height and 5 cm in diameter, as shown in Fig. 2. A CR-39 detector with a thickness of 1 mm, a density of 0.32 $gm/m^3$, and dimensions of 2.5 cm × 2.5 cm was fixed at the top of a plastic container. The containers were tightly sealed with covers for an exposure period to radon for 90 days.

After the exposure period, the detectors were removed from the containers and placed in a solution of 6.25N NaOH in a water bath at 98° C for one hour [5]. The detectors were then removed from the bath, properly rinsed, and cleaned using distilled water to remove digging leftovers from the surface. Following the chemical process, these detectors were dried and scanned with an optical microscope at a magnification of 400X to calculate the number of tracks per $cm^2$ for each detector according to the following equation [6].

$$\text{The density of tracks } (\rho) = \frac{number\ of\ tracks\ in\ sample}{Area\ of\ field\ view} \quad (1)$$

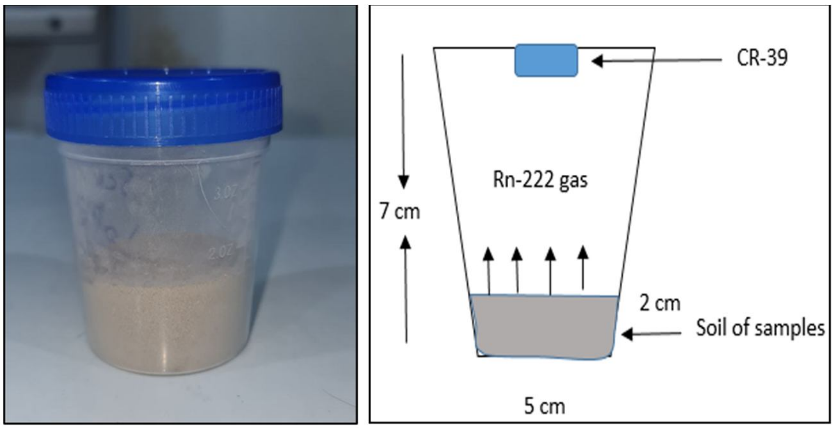


FIG. 2. The radon dosimeter used in this study.

### 3.1 Theoretical Considerations

The closed container's radon concentration (C) can be calculated as [7]:

$$C\left(\frac{Bq}{m^3}\right) = \frac{\rho}{K\,T} \quad (2)$$

where K represents the calibration factor for the CR-39 detector (K= 0.28±0.043 $Track.cm^{-2}$ $/Bq.m^{-3.}day$). The calibration of the CR-39 detector was determined using a standard source of $^{226}Ra$ (radon source) with exposure times of 0.5, 1, 1.5, 2, 2.5, and 3 days. T is the exposure time (90 days).

The radon concentration ($C_{Rn}$) in the soil samples can be calculated as [8]:

$$C_{Rn}\left(\frac{Bq}{m^3}\right) = \frac{C\,\lambda_{Rn}\,h\,T}{l} \quad (3)$$

where $\lambda_{Rn}$ represents the radon decay constant, h is the distance between the soil sample and the CR-39 detector, and $l$ is the soil sample thickness in the container.

The specific activity of $^{226}Ra$, $^{226}C_{Ra}$, in the soil samples can be determined using the following equation [9]:

$$C_{Ra}\left(\frac{Bq}{kg}\right) = \frac{C\,h\,A}{M} \quad (4)$$

where the distance between the soil surface of the sample inside the container and the CR39 detector is given by h, A is the sample's surface area, and M is the sample's mass.

Using the secular equilibrium property of uranium-238 and radon-222, we can find the uranium-238 concentrations ($C_U$) in units ppm, which depend on the mass of uranium-238 ($M_U$) and mass of the soil sample (M), as follows [8, 10]:

$$C_U(ppm) = \frac{M_U(mg)}{M\,(kgm)} \quad (5)$$

The annual effective dose (AED) was determined using the following relation [8]:

$$AED\left(\frac{mSv}{y}\right) = 0.4 \times 0.8 \times 8760 \times 9.0 \times 10^{-6}\,C \quad (6)$$

where 0.4 is the equilibrium factor, 0.8 is the occupancy factor for residents, 8760 is the number of hours in a year, $9\times10^{-6}$ $mSv/ Bq.h.m^{-3}$ is the dose effective factor, and C is the indoor Rn concentration factor.

Also, radon surface exhalation rate ($E_S$) and mass exhalation rate ($E_M$) were evaluated using the following formulas [8, 10]:

$$E_S = \frac{C\,V\,\lambda}{A\,T_e} \quad (7)$$

$$E_M = \frac{C\,V\,\lambda}{M\,T_e} \quad (8)$$

where V is the air volume in the cup in $m^3$ and $T_e$ is the effective exposure time, determined by employing the formula [11]:

$$T_e = T - \frac{1}{\lambda}\left(1 - e^{-\lambda T}\right) \quad (9)$$

## 4. Results and Discussion

The radon concentration (C) results in the closed container, radon concentration ($C_{Rn}$) in the soil samples, the specific activity of $^{226}$Ra ($C_{Ra}$), and uranium-238 concentrations ($C_U$) are presented in Table 2. The radon concentration in the air space of the container varied from 7.47Bq/$m^3$ in school P5 to 66.51 Bq/$m^3$ in school P74, with an average value of 23.53±1.149Bq/$m^3$. The $C_{Rn}$ values ranged from 305.02 to 2714.66 Bq/$m^3$, with an average of 960.38±47 Bq/$m^3$. The maximum values of both C and $C_{Rn}$ are lower than the world average for radon gas in air, which is 100 Bq/$m^3$ according to WHO [12] and 7400 Bq/$m^3$ [8, 13].

The specific activity of $^{226}$Ra showed a minimum value of 0.011 Bq/kg in school P5 and a maximum value of 0.099 Bq/kg in school P74, with an average of 0.035±0.002 Bq/kg. The uranium-238 concentrations ($C_U$) varied from 0.014 to 0.123 ppm, with an average value of 0.043±0.002 ppm. The maximum values of $C_{Ra}$ and $C_U$ were below the global average values of 35 Bq/kg for $C_{Ra}$ [14] and 11 mg/kg (ppm) for uranium-238 concentrations [15].

Fig. 3 illustrates the concentration of radon in the air space of the container, showing that all results were below the worldwide level. Figure 4 shows the histograms of the distribution of radon concentration in both air space and soil samples within the container, specific activity of $^{226}$Ra, and concentration of $^{238}$U. These distributions exhibit a normal (bell-shaped) distribution pattern.

TABLE 2. The radon concentration (C) in the closed container, the radon concentration in the soil samples ($C_{Rn}$), specific activity of $^{226}$Ra,($^{226}C_{Ra}$), and the uranium-238 concentrations ($C_U$) for studied schools.

| Sample code | C (Bq/$m^3$) | $C_{Rn}$(Bq/$m^3$) | $C_{Ra}$(Bq/kg) | $C_U$(ppm) |
|---|---|---|---|---|
| P 1 | 19.43 | 793.05 | 0.029 | 0.036 |
| P 2 | 14.87 | 606.98 | 0.022 | 0.027 |
| P 3 | 31.39 | 1281.07 | 0.047 | 0.058 |
| P 4 | 16.44 | 671.04 | 0.025 | 0.030 |
| P 5 | 7.47 | 305.02 | 0.011 | 0.014 |
| P 6 | 25.41 | 1037.06 | 0.038 | 0.047 |
| P 7 | 23.91 | 976.06 | 0.036 | 0.044 |
| P 8 | 35.87 | 1464.08 | 0.054 | 0.066 |
| P 9 | 25.41 | 1037.06 | 0.038 | 0.047 |
| P 10 | 28.40 | 1159.07 | 0.042 | 0.052 |
| P 11 | 8.22 | 335.52 | 0.012 | 0.015 |
| P 12 | 52.31 | 2135.12 | 0.078 | 0.097 |
| P 13 | 16.44 | 671.04 | 0.025 | 0.030 |
| P 14 | 17.94 | 732.04 | 0.027 | 0.033 |
| P 15 | 23.91 | 976.06 | 0.036 | 0.044 |
| P 16 | 16.44 | 671.04 | 0.025 | 0.030 |
| P 17 | 58.29 | 2379.14 | 0.087 | 0.108 |
| P 18 | 17.94 | 732.04 | 0.027 | 0.033 |
| P 19 | 16.44 | 671.04 | 0.025 | 0.030 |
| P 20 | 26.90 | 1098.06 | 0.040 | 0.050 |
| P 21 | 13.45 | 549.03 | 0.020 | 0.025 |
| P 22 | 23.91 | 976.06 | 0.036 | 0.044 |
| P 23 | 15.77 | 643.59 | 0.024 | 0.029 |
| P 24 | 15.69 | 640.54 | 0.023 | 0.029 |
| P 25 | 16.59 | 677.14 | 0.025 | 0.031 |
| P 26 | 28.40 | 1159.07 | 0.042 | 0.052 |
| P 27 | 26.53 | 1082.81 | 0.040 | 0.049 |
| P 28 | 21.52 | 878.45 | 0.032 | 0.040 |
| P 29 | 20.92 | 854.05 | 0.031 | 0.039 |
| P 30 | 19.95 | 814.40 | 0.030 | 0.037 |

| Sample code | C ($Bq/m^3$) | $C_{Rn}$($Bq/m^3$) | $C_{Ra}$(Bq/kg) | $C_U$(ppm) |
|---|---|---|---|---|
| P 31 | 20.92 | 854.05 | 0.031 | 0.039 |
| P 32 | 35.72 | 1457.98 | 0.053 | 0.066 |
| P 33 | 11.96 | 488.03 | 0.018 | 0.022 |
| P 34 | 14.95 | 610.03 | 0.022 | 0.028 |
| P 35 | 22.42 | 915.05 | 0.033 | 0.041 |
| P 36 | 17.94 | 732.04 | 0.027 | 0.033 |
| P 37 | 35.12 | 1433.58 | 0.052 | 0.065 |
| P 38 | 37.37 | 1525.09 | 0.056 | 0.069 |
| P 39 | 17.94 | 732.04 | 0.027 | 0.033 |
| P 40 | 23.91 | 976.06 | 0.036 | 0.044 |
| P 41 | 16.44 | 671.04 | 0.025 | 0.030 |
| P 42 | 17.41 | 710.69 | 0.026 | 0.032 |
| P 43 | 44.84 | 1830.10 | 0.067 | 0.083 |
| P 44 | 41.10 | 1677.60 | 0.061 | 0.076 |
| P 45 | 26.90 | 1098.06 | 0.040 | 0.050 |
| P 46 | 26.90 | 1098.06 | 0.040 | 0.050 |
| P 47 | 48.58 | 1982.61 | 0.073 | 0.090 |
| P 48 | 14.95 | 610.03 | 0.022 | 0.028 |
| P 49 | 11.96 | 488.03 | 0.018 | 0.022 |
| P 50 | 13.45 | 549.03 | 0.020 | 0.025 |
| P 51 | 11.96 | 488.03 | 0.018 | 0.022 |
| P 52 | 10.46 | 427.02 | 0.016 | 0.019 |
| P 53 | 26.16 | 1067.56 | 0.039 | 0.048 |
| P 54 | 16.44 | 671.04 | 0.025 | 0.030 |
| P 55 | 12.70 | 518.53 | 0.019 | 0.023 |
| P 56 | 23.91 | 976.06 | 0.036 | 0.044 |
| P 57 | 20.92 | 854.05 | 0.031 | 0.039 |
| P 58 | 46.33 | 1891.11 | 0.069 | 0.086 |
| P 59 | 19.43 | 793.05 | 0.029 | 0.036 |
| P 60 | 20.92 | 854.05 | 0.031 | 0.039 |
| P 61 | 25.41 | 1037.06 | 0.038 | 0.047 |
| P 62 | 23.17 | 945.55 | 0.035 | 0.043 |
| P 63 | 31.39 | 1281.07 | 0.047 | 0.058 |
| P 64 | 21.67 | 884.55 | 0.032 | 0.040 |
| P 65 | 16.44 | 671.04 | 0.025 | 0.030 |
| P 66 | 11.96 | 488.03 | 0.018 | 0.022 |
| P 67 | 20.92 | 854.05 | 0.031 | 0.039 |
| P 68 | 23.91 | 976.06 | 0.036 | 0.044 |
| P 69 | 25.41 | 1037.06 | 0.038 | 0.047 |
| P 70 | 23.91 | 976.06 | 0.036 | 0.044 |
| P 71 | 20.92 | 854.05 | 0.031 | 0.039 |
| P 72 | 20.92 | 854.05 | 0.031 | 0.039 |
| P 73 | 52.31 | 2135.12 | 0.078 | 0.097 |
| P 74 | 66.51 | 2714.66 | 0.099 | 0.123 |
| P 75 | 20.92 | 854.05 | 0.031 | 0.039 |
| P 76 | 56.05 | 2287.63 | 0.084 | 0.103 |
| P 77 | 25.41 | 1037.06 | 0.038 | 0.047 |
| P 78 | 35.87 | 1464.08 | 0.054 | 0.066 |
| P 79 | 28.40 | 1159.07 | 0.042 | 0.052 |
| P 80 | 20.92 | 854.05 | 0.031 | 0.039 |
| P 81 | 31.39 | 1281.07 | 0.047 | 0.058 |
| P 82 | 16.44 | 671.04 | 0.025 | 0.030 |
| P 83 | 10.84 | 442.28 | 0.016 | 0.020 |
| P 84 | 13.45 | 549.03 | 0.020 | 0.025 |
| P 85 | 11.96 | 488.03 | 0.018 | 0.022 |
| P 86 | 14.20 | 579.53 | 0.021 | 0.026 |
| P 87 | 32.88 | 1342.08 | 0.049 | 0.061 |
| P 88 | 43.34 | 1769.10 | 0.065 | 0.080 |
| P 89 | 20.92 | 854.05 | 0.031 | 0.039 |

| Sample code | C (Bq/m$^3$) | $C_{Rn}$(Bq/m$^3$) | $C_{Ra}$(Bq/kg) | $C_U$(ppm) |
|---|---|---|---|---|
| P 90 | 20.92 | 854.05 | 0.031 | 0.039 |
| P 91 | 9.72 | 396.52 | 0.015 | 0.018 |
| P 92 | 13.45 | 549.03 | 0.020 | 0.025 |
| P 93 | 25.41 | 1037.06 | 0.038 | 0.047 |
| P 94 | 22.42 | 915.05 | 0.033 | 0.041 |
| P 95 | 13.45 | 549.03 | 0.020 | 0.025 |
| P 96 | 8.22 | 335.52 | 0.012 | 0.015 |
| P 97 | 25.41 | 1037.06 | 0.038 | 0.047 |
| P 98 | 23.24 | 948.60 | 0.035 | 0.043 |
| P 99 | 13.23 | 539.88 | 0.020 | 0.024 |
| P 100 | 13.45 | 549.03 | 0.020 | 0.025 |
| Minimum | 7.47 | 305.02 | 0.011 | 0.014 |
| Maximum | 66.51 | 2714.66 | 0.099 | 0.123 |
| Average±S.E | 23.53 ±1.149 | 960.38±47 | 0.035±0.002 | 0.043±0.002 |

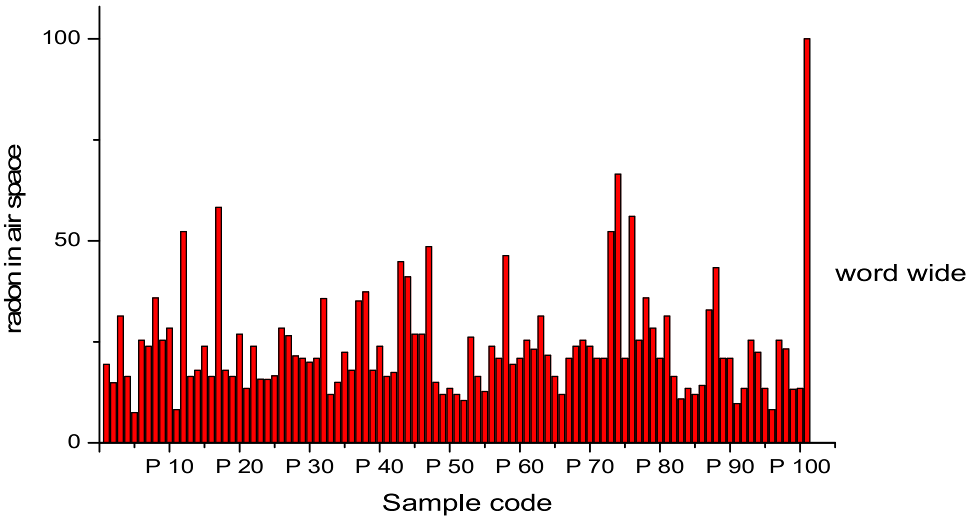


FIG. 3. Radon concentration in the air space of the container for the studied schools and worldwide.

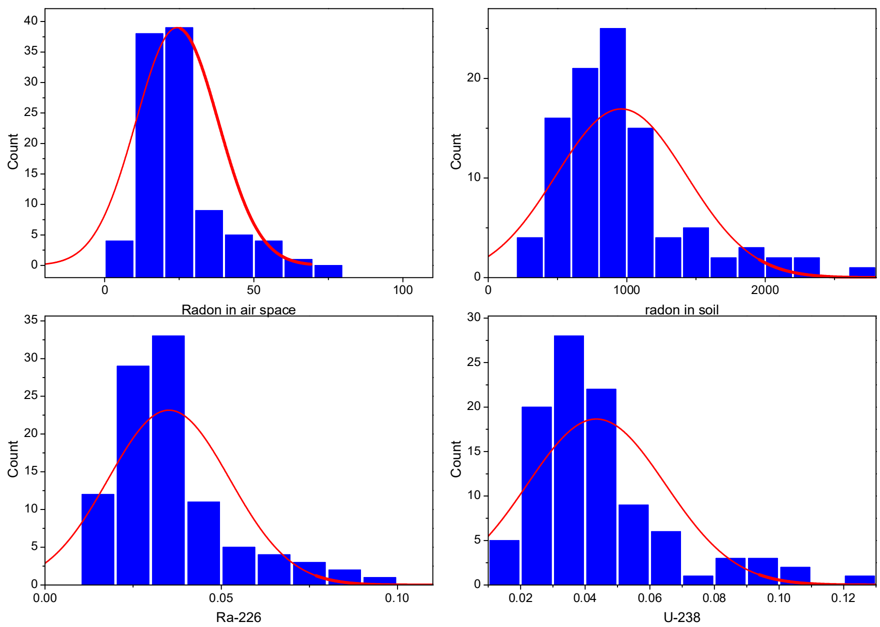


FIG. 4. The histogram of the C, $C_{Rn}$, $C_{Ra}$, and $C_U$ concentrations distribution in the selected schools.

The dose obtained by the students and staff in the studied schools was calculated using the annual effective dose related to radon concentrations, as described by Eq. (6). Table 3 displays the results of the AED and radon exhalation rate per unit mass ($E_M$) and per unit surface ($E_S$) for studied schools. The AED values ranged from 0.189 to 1.678 mSv/y, with a mean of 0.59±0.029 mSv/y.

The AED values for all studied schools were within the action levels set by the ICRP (3–10 mSv/y) [16] and by the UNSCEAR (1.2 mSv/y) [17]. However, exceptions were noted in samples P12, P17, P47, P73, P74, and P76, as shown in Fig. 5.

The radon exhalation rate per unit mass ($E_M$) values varied from 0.059 to 0.528 mBq/kg.h with an average of 0.19±0.009 mBq/kg.h.

The radon exhalation rate per unit surface ($E_s$) values ranged from 2.076 to 18.475 mBq/m$^2$.h, with an average of 6.54±0.319 mBq/m$^2$.h. The study showed that the radon exhalation rates varied according to radon concentrations inside the container. Also, it was found that all values of $E_S$ in the present study were below the action level of 57.6 Bqm$^2$.h [17].

TABLE 3. The annual effective dose (AED), mass exhalation rate ($E_M$), and surface exhalation rate for monitored schools.

| Sample code | AED (mSv/y) | $E_M$ (mBq/kg.h) | $E_S$ (mBq/m$^2$.h) |
|---|---|---|---|
| P 1 | 0.490 | 0.154 | 5.397 |
| P 2 | 0.375 | 0.118 | 4.131 |
| P 3 | 0.792 | 0.249 | 8.719 |
| P 4 | 0.415 | 0.130 | 4.567 |
| P 5 | 0.189 | 0.059 | 2.076 |
| P 6 | 0.641 | 0.202 | 7.058 |
| P 7 | 0.603 | 0.190 | 6.643 |
| P 8 | 0.905 | 0.285 | 9.964 |
| P 9 | 0.641 | 0.202 | 7.058 |
| P 10 | 0.716 | 0.225 | 7.888 |
| P 11 | 0.207 | 0.065 | 2.283 |
| P 12 | 1.320 | 0.415 | 14.531 |
| P 13 | 0.415 | 0.130 | 4.567 |
| P 14 | 0.452 | 0.142 | 4.982 |
| P 15 | 0.603 | 0.190 | 6.643 |
| P 16 | 0.415 | 0.130 | 4.567 |
| P 17 | 1.471 | 0.463 | 16.192 |
| P 18 | 0.452 | 0.142 | 4.982 |
| P 19 | 0.415 | 0.130 | 4.567 |
| P 20 | 0.679 | 0.214 | 7.473 |
| P 21 | 0.339 | 0.107 | 3.737 |
| P 22 | 0.603 | 0.190 | 6.643 |
| P 23 | 0.398 | 0.125 | 4.380 |
| P 24 | 0.396 | 0.125 | 4.359 |
| P 25 | 0.419 | 0.132 | 4.608 |
| P 26 | 0.716 | 0.225 | 7.888 |
| P 27 | 0.669 | 0.211 | 7.369 |
| P 28 | 0.543 | 0.171 | 5.979 |
| P 29 | 0.528 | 0.166 | 5.812 |
| P 30 | 0.503 | 0.158 | 5.543 |
| P 31 | 0.528 | 0.166 | 5.812 |
| P 32 | 0.901 | 0.284 | 9.923 |
| P 33 | 0.302 | 0.095 | 3.321 |
| P 34 | 0.377 | 0.119 | 4.152 |
| P 35 | 0.566 | 0.178 | 6.228 |
| P 36 | 0.452 | 0.142 | 4.982 |
| P 37 | 0.886 | 0.279 | 9.757 |
| P 38 | 0.943 | 0.297 | 10.379 |
| P 39 | 0.452 | 0.142 | 4.982 |
| P 40 | 0.603 | 0.190 | 6.643 |
| P 41 | 0.415 | 0.130 | 4.567 |
| P 42 | 0.439 | 0.138 | 4.837 |
| P 43 | 1.131 | 0.356 | 12.455 |
| P 44 | 1.037 | 0.326 | 11.417 |

| Sample code | AED (mSv/y) | $E_M$ (mBq/kg.h) | $E_S$ (mBq/m$^2$.h) |
|---|---|---|---|
| P 45 | 0.679 | 0.214 | 7.473 |
| P 46 | 0.679 | 0.214 | 7.473 |
| P 47 | 1.226 | 0.386 | 13.493 |
| P 48 | 0.377 | 0.119 | 4.152 |
| P 49 | 0.302 | 0.095 | 3.321 |
| P 50 | 0.339 | 0.107 | 3.737 |
| P 51 | 0.302 | 0.095 | 3.321 |
| P 52 | 0.264 | 0.083 | 2.906 |
| P 53 | 0.660 | 0.208 | 7.266 |
| P 54 | 0.415 | 0.130 | 4.567 |
| P 55 | 0.321 | 0.101 | 3.529 |
| P 56 | 0.603 | 0.190 | 6.643 |
| P 57 | 0.528 | 0.166 | 5.812 |
| P 58 | 1.169 | 0.368 | 12.870 |
| P 59 | 0.490 | 0.154 | 5.397 |
| P 60 | 0.528 | 0.166 | 5.812 |
| P 61 | 0.641 | 0.202 | 7.058 |
| P 62 | 0.584 | 0.184 | 6.435 |
| P 63 | 0.792 | 0.249 | 8.719 |
| P 64 | 0.547 | 0.172 | 6.020 |
| P 65 | 0.415 | 0.130 | 4.567 |
| P 66 | 0.302 | 0.095 | 3.321 |
| P 67 | 0.528 | 0.166 | 5.812 |
| P 68 | 0.603 | 0.190 | 6.643 |
| P 69 | 0.641 | 0.202 | 7.058 |
| P 70 | 0.603 | 0.190 | 6.643 |
| P 71 | 0.528 | 0.166 | 5.812 |
| P 72 | 0.528 | 0.166 | 5.812 |
| P 73 | 1.320 | 0.415 | 14.531 |
| P 74 | 1.678 | 0.528 | 18.475 |
| P 75 | 0.528 | 0.166 | 5.812 |
| P 76 | 1.414 | 0.445 | 15.569 |
| P 77 | 0.641 | 0.202 | 7.058 |
| P 78 | 0.905 | 0.285 | 9.964 |
| P 79 | 0.716 | 0.225 | 7.888 |
| P 80 | 0.528 | 0.166 | 5.812 |
| P 81 | 0.792 | 0.249 | 8.719 |
| P 82 | 0.415 | 0.130 | 4.567 |
| P 83 | 0.273 | 0.086 | 3.010 |
| P 84 | 0.339 | 0.107 | 3.737 |
| P 85 | 0.302 | 0.095 | 3.321 |
| P 86 | 0.358 | 0.113 | 3.944 |
| P 87 | 0.830 | 0.261 | 9.134 |
| P 88 | 1.094 | 0.344 | 12.040 |
| P 89 | 0.528 | 0.166 | 5.812 |
| P 90 | 0.528 | 0.166 | 5.812 |
| P 91 | 0.245 | 0.077 | 2.699 |
| P 92 | 0.339 | 0.107 | 3.737 |
| P 93 | 0.641 | 0.202 | 7.058 |
| P 94 | 0.566 | 0.178 | 6.228 |
| P 95 | 0.339 | 0.107 | 3.737 |
| P 96 | 0.207 | 0.065 | 2.283 |
| P 97 | 0.641 | 0.202 | 7.058 |
| P 98 | 0.586 | 0.184 | 6.456 |
| P 99 | 0.334 | 0.105 | 3.674 |
| P 100 | 0.339 | 0.107 | 3.737 |
| Minimum | 0.189 | 0.059 | 2.076 |
| Maximum | 1.678 | 0.528 | 18.475 |
| Average±S.E | 0.59 ±0.029 | 0.19 ±0.009 | 6.54 ±0.319 |

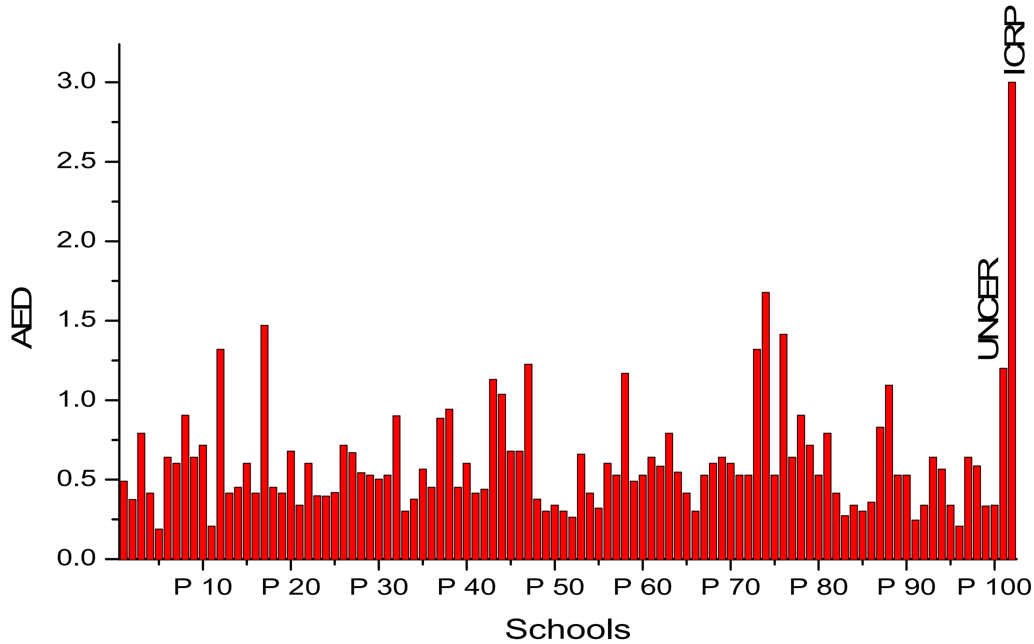


FIG. 5. The annual effective dose (AED) for measured schools, UNSCEAR, and ICRP.

The differences in the measurement of radon concentration among the soil samples from the studied schools under study are attributed to the varying concentrations of $^{238}U$ and $^{226}Ra$ within these soils. Schools with higher $^{238}U$ and $^{226}Ra$ content in the soil exhibit increased exhalation rates, as illustrated in Fig. 5. Also, these differences depend on the density, porosity, permeability, grain size of the soil samples, and other factors.

Fig. 6 shows the correlation between the $^{226}Ra$ concentration in the soil samples and the radon exhalation rates ($E_M$ and $E_s$) for the investigated schools. The figure demonstrates a linear relationship between the $^{226}Ra$ content and exhalation rates, with a correlation coefficient of 0.999 for both.

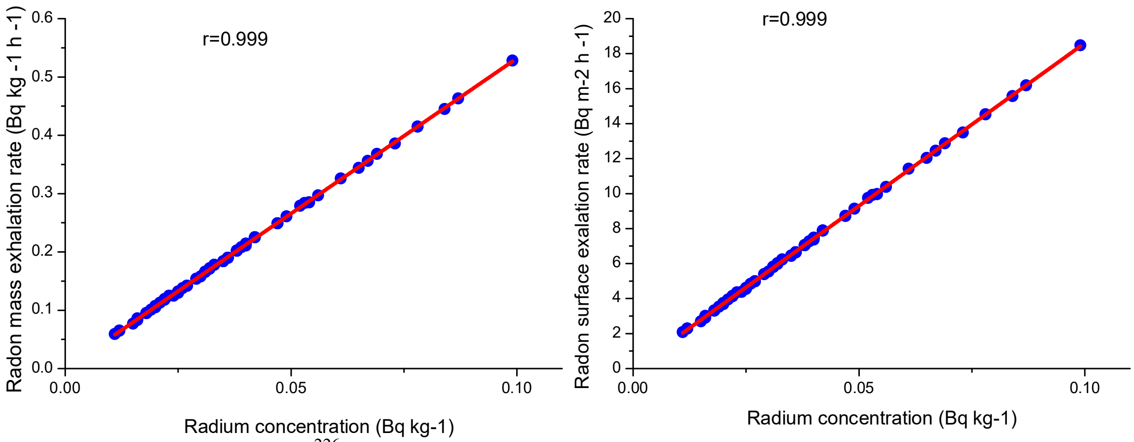


FIG. 6. The correlation between $^{226}Ra$ concentration and radon exhalation rates (EM and Es) for the investigated schools.

## Conclusions

The study of radon concentration in the air and soil of containers with soil samples in primary schools in Najaf indicates normal levels. The average C, $C_{Rn}$, $226C_{Ra}$, and $C_U$ values are significantly lower than the worldwide limit. The results of the surface exhalation rate ($E_s$) are lower than the global limit. The measurements of the AED for the studied schools are lower than those recommended by the ICRP and the results of UNSCEAR, except for samples P12, P17, P47, P73, P74, and P76. Consequently, the occupants of these schools (children and staff) are not at risk of radiological exposure from their immediate surroundings.

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