The determination of equilibrium factor of radon and thoron using LR-115 type II detector in a selected area from Basra Governorate, Iraq

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Abstract. The inhalations of radon $^{222}$Rn progeny are the most important source of irradiation of the human respiratory. Studies of underground miners of uranium and other minerals have provided reasonably firm estimates of the risk of lung cancer associated with exposure to radon progeny. It is well established that the absorbed radon dose in the lung is mainly due to radon progeny, but not the radon gas itself. Therefore, long-term measurements of the concentrations of radon progeny or the equilibrium factor $F$, together with a measurement or an estimation of the aerosol size distribution, are needed to accurately assess the health hazards contribution from radon progeny. Radon, thoron and their progeny are present in the indoor atmosphere as free and bound fractions. The ventilation level in the house played an important effect on the equilibrium between them. This paper presents the results of the measurement of the equilibrium factor $F$ between radon, thoron and their progenies in dwellings and estimates a theoretical relationship for the $F$-factor based on track density instead of typical value of UNISCEAR (about 0.4), which varies significantly with time and place. In this paper, we described a method of theoretical calculation of $F$ and experimentally determined the $F$-factor using LR-115 type-2 plastic track detectors in closed and bare mod. The exposures were made with a cup and bare dosimeters distributed in 34 houses distributed in different locations of Basra Governorate. The measured $F$-factor between radon and progeny varied from 0.01 to 0.98 with an average value of 0.38 while the same factor for thoron and progeny was found to vary from 0.0004 to 0.3794 with an average value of 0.0877. These values were in a good agreement with the global $F$-factor estimated by ICRP. In present investigation about the $F$-factor, theoretical calculations using graphical solutions supported by experimental technique have been carried out. It is found that the globally assumed $F$-factor from UNSCEAR and our experimentally obtained value are in good agreement. For a more accurate estimation of the effective dose, one should measure the $F$-factor at each site considering all the effective parameters like the ventilation factors. The equilibrium factor was found to be small in some houses due to the very intensive ventilation system in the house.

1. Introduction
The inhalations of radon $^{222}$Rn progeny are the most important source of irradiation of the human respiratory. Studies of underground miners of uranium and other minerals have provided reasonably firm estimates of the risk of lung cancer associated with exposure to radon progeny. It is well established that the absorbed radon dose in the lung is mainly due to radon progeny, but not the radon gas itself. Therefore, long-term measurements of the concentrations of radon progeny or the equilibrium factor $F$, together with a measurement or an estimation of the aerosol size distribution, are needed to accurately assess the health hazards contribution from radon progeny [1]. In the recent years; several techniques have been developed to measure indoors radon gas concentration. The use of a Solid State Nuclear Track Detector (SSNTD) closed in a cup mode and bare mode were turned out to be the most appropriate methods for long term and accurate measurements [2]. In the case of the bare mode, there exist large uncertainties due to the fact that the calibration factor $K$ depends on the
equilibrium factor between radon gas and progenies. One usually needs to determine radon concentration independently on the equilibrium factor. In this case one can use a diffusion chamber in which the opening is covered with a filter paper, thin sponge or some other permeable foil [3]. A common procedure for the method is to determine the radon gas concentration firstly and then apply an assumed F-factor with a typical value of about 0.4 [UNISCEAR 2009][4]. However, in reality, F varies significantly with time and place and the assumption that F is constant is not reflecting the actual conditions. This problem cannot be solved through active measurements based on air filtering since they only give short-term determinations. The long term measurements of radon progenies or equilibrium factor using the SSNTDs are more accurate radon concentration measurements [5]. Frank and Benton 1977 [4] proposed a method for determination of the equilibrium factor[5-7]. In this method, they used cellulose nitrate detectors one in a diffusion chamber and the other as an open detector. The second detector was registered tracks from the decay of radon and thoron and their progenies, while the first one registered tracks from the decay of $^{222}$Rn. The ratio between the readings for the open and closed detectors was related to F factor [5-7]. As shown earlier, the sensitivity of the closed detector depends on the chamber shape and dimension and may be very different from the sensitivity of an open detector. However the equilibrium factor also depends on the ventilation rate of the places of measurement as proposed in reference [8].

In this paper, we described a method of theoretical calculation of the equilibrium factor and experimentally determined the equilibrium factor using LR-115 type-2 detectors in closed and bare modes.

2. Theoretical approaches
The equilibrium F is defined as the ratio of the $^{222}$Rn ($^{220}$Th) progenies to the $^{222}$Rn ($^{220}$Th) concentration in air. F=1 for complete radioactive equilibrium between $^{222}$Rn ($^{220}$Th) and its progeny, and F=0 for pure gas with no daughter. F can be found as the ratio between track densities of bare to the closed detectors [9]. The potential alpha energy concentration (PAEC) of any mixture of (short-lived) radon or thoron daughters in air is the sum of the potential alpha energies of all daughters atoms present per unit volume of air. The usual unit for this quantity is MeV.l$^{-1}$. This unit is related to the SI units J and m$^3$ according to 1J.m$^{-3}$=6.24 x 10$^9$ MeV.l$^{-1}$[10]. To express this mathematically we write;

$$(PAEC)_{total} = PAEC_1 N_1 + PAEC_2 N_2 + PAEC_3 N_3 + PAEC_4 N_4$$

where PAEC is the total Potential Alpha Energy Concentration of any mixture of the short-lived radon daughters in air, $PAEC_i$ (i=1,4) are the potential alpha energy concentration for $^{218}$Po, $^{214}$Pb, $^{214}$Bi and $^{214}$Po, respectively, $N_i$ are the number of atoms. The activity is defined as:

$$A_i = \lambda_i N_i$$

The potential alpha energy concentration is defined as:

$$C_{PAEC} = \frac{PAEC}{Volume}$$

$$C_{PAEC} = \left[ \frac{PAEC_1}{\lambda_1} f_1 + \frac{PAEC_2}{\lambda_2} f_2 + \frac{PAEC_3}{\lambda_3} f_3 + \frac{PAEC_4}{\lambda_4} f_4 \right] C_0$$

where

$$f_i = \frac{C_i}{C_0}; \quad C_0 = C_{Rn}$$

$f_i$ is the activity concentration fraction.
Historically, the PAEC of radon radioactivity was expressed in the unit of Working Level (WL). WL is the normal unit for expressing radon and short lived daughter exposure rate in air. An approximate value of WL is 3.7 kBq.m\(^{-3}\)[10].

\[ C_1 = C_2 = C_3 = C_4 = C_0 = C_{rn} = 3.7 \text{ kBq} \cdot \text{m}^{-3} = 3.7 \text{Bq.} \text{l}^{-1} \]  

(6)

Eq. (4) becomes:

\[ C_{PAEC} = WL = \frac{3.7 PAEC_1}{\lambda_1} + \frac{3.7 PAEC_2}{\lambda_2} + \frac{3.7 PAEC_3}{\lambda_3} + \frac{3.7 PAEC_4}{\lambda_4} = 1.3 \times 10^5 \text{MeV.l}^{-1} \]  

(7)

Table 1 shows the energy distribution per liter of radon gas.

| daughters of radon | \( \alpha \)-energy (MeV) | half-life (Sec) | ultimate alpha energy (MeV) | Total energy (MeV) | Fraction energy |
|-------------------|--------------------------|----------------|-----------------------------|-------------------|----------------|
| Po-218 (\( \alpha \)) | 6 | 183 | 6+7.69 | 1.34E+04 | 0.11 |
| Pb-214 (\( \beta \)) | 0 | 1563 | 0+7.68 | 6.41E+04 | 0.51 |
| Bi-214 (\( \beta \)) | 0 | 1182 | 0+7.68 | 4.85E+04 | 0.38 |
| Po-214 (\( \alpha \)) | 7.69 | 1.64E-04 | 7.68 | 6.72E-03 | 0.00 |

To obtain the concentration potential alpha energy by fraction energy, Eq. (4) multiply and divide by 3.7 Bq.l\(^{-1}\) and multiply and divide by 1.3 \times 10^5 Mev.l\(^{-1}\), i.e.

\[ C_{PAEC} = \left[ \frac{3.7 PAEC_1}{1.3 \times 10^5} f_1 + \frac{3.7 PAEC_2}{1.3 \times 10^5} f_2 + \frac{3.7 PAEC_3}{1.3 \times 10^5} f_3 + \frac{3.7 PAEC_4}{1.3 \times 10^5} f_4 \right] \frac{1.3 \times 10^5}{3.7} C_{Rn} \]  

(8)

The concentration potential alpha energy by unit mWL is:

\[ C_{PAEC(mWL)} = \frac{F_{Rn} C_{Rn}}{3.7} \]  

(9)

where \( F_{Rn} = 0.11 f_1 + 0.51 f_2 + 0.38 f_3 \)  

(10)

One working level was originally defined as the concentration of potential alpha energy associated with radon progenies in equilibrium with radon concentration of 3700 Bq/m\(^3\), which corresponds to 1.3 \times 10^5 Mev.l\(^{-1}\). The concentration of thoron which give potential energy of alpha associated with its daughters equal to 1.3 \times 10^5 Mev.l\(^{-1}\) is 0.275 Bq.l\(^{-1}\), as shown in Table 2.
Table 2. Calculated thoron concentration corresponding to $1.3 \times 10^5 \text{MeV.l}^1$.

| daughters of thoron | $\alpha$-energy (MeV) | half-life (Sec) | ultimate alpha energy(MeV) | Total energy (MeV) | $C_{Tn}$ (Bq.l$^1$) |
|----------------------|------------------------|-----------------|-----------------------------|-------------------|---------------------|
| Po-216 ($\alpha$)   | 6.78                   | 0.15            | 14.5952                     | 3.16E+00          | 0.275               |
| Pb-212 ($\beta$)    | 0                      | 38304           | 7.8152                      | 4.32E+05          |                     |
| Bi-212 ($\alpha$)   | 6.1                    | 3636            | 7.8152                      | 4.10E+04          |                     |
| Po-212 ($\alpha$)   | 8.78                   | 3.04E-07        | 8.78                        | 3.85E-06          | 4.73E+05            |

By the same steps, we derive the concentration potential alpha energy by unit $mWL$ for thoron (Eq.11) and presented the data in Table (3).

Table 3. The results of PAEC calculation for thoron

| daughters of Thoron | $\alpha$-energy (MeV) | half-life (Sec) | ultimate alpha energy(MeV) | Total energy (MeV) | Fraction energy |
|---------------------|------------------------|-----------------|-----------------------------|-------------------|-----------------|
| Po-216 ($\alpha$)  | 6.78                   | 0.15            | 14.5952                     | 8.69E-01          | 0.00            |
| Pb-212 ($\beta$)   | 0                      | 38304           | 7.8152                      | 1.19E+05          | 0.91            |
| Bi-212 ($\alpha$)  | 6.1                    | 3636            | 7.8152                      | 1.13E+04          | 0.09            |
| Po-212 ($\alpha$)  | 8.78                   | 3.04E-07        | 8.78                        | 1.06E-06          | 1.3E+05         |

$$C_{PAEC}(mWL) = \frac{F_{Tn} C_{Tn}}{0.275}$$  \hspace{1cm} (11)

where \( F_{Tn} = 0.91 f_2 + 0.09 f_3 \) \hspace{1cm} (12)

\( F_{Rn} \) and \( F_{Tn} \) are the equilibrium factor for radon and thoron, respectively. The equilibrium factor \( F \) of a given mixture of radon/ thoron progenies in air is defined as the ratio of the total potential alpha energy in WL for the actual daughter concentration to the total potential alpha energy of the daughters which would be in equilibrium with the radon or thoron concentration.

In this work, we measured the equilibrium factor depending on the ventilation rate, which is the rate one of the parameter used to described the perturbation caused in radioactive equilibrium of radon/thoron and its descendants in air [11]. The rate of radon production can be described by the rate equations for serial radioactive decay chain (Batman equations):

$$\frac{dN_i}{dt} = - \Lambda_i N_i + \Lambda_{i-1} N_{i-1} \hspace{1cm} (i=1\ldots4)$$  \hspace{1cm} (13)

where \( \Lambda_i = V + A_i + W_i + \lambda_i \) \hspace{1cm} (14)

The first term on the right is the rate of formation of the \( i^{th} \)-member of the progeny by radioactive decay of the \((i-1)^{th}\)-member, with constant \( \lambda_{i-1} \); the second term describes the radioactive leakage rate, owing to ventilation \( V \), to aerosol grains \( A_i \) and deposition on the walls \( W_i \), to which it added the rate of radioactive decay of the \( i^{th} \)-member of the progeny, \( \lambda_i \) [11]. The index \( i \), running from 1 to 4, label the
relevant daughter in the radon family: $^{218}\text{Po}$, $^{214}\text{Pb}$, $^{214}\text{Bi}$, $^{214}\text{Po}$, while $^{222}\text{Rn}$ itself will be labelled with $i=0$ [11]. For thoron family: $^{216}\text{Po}$, $^{212}\text{Pb}$, $^{212}\text{Bi}$, $^{212}\text{Po}$, while $^{220}\text{Rn}$ (Tn) itself will be labelled with $i=0$.

Ventilation rate affects equally all members of the decay family. When steady state is reached, radon daughter’s activity in Eq. (13) becomes;

$$\lambda_{i-1} N_{i-1} = \Lambda_i N_i$$  \hspace{1cm} (15)

$$\therefore N = \frac{A}{\lambda} = \frac{V C}{\lambda}$$  \hspace{1cm} (16)

Eq. (15) becomes as:

$$\frac{c_i}{c_{i-1}} = \frac{\lambda_i}{\Lambda_i} = d_i$$  \hspace{1cm} (17)

From Eq. (17) we obtain:

$$f_1 = \frac{c_1}{c_0} = d_1$$

$$f_2 = \frac{c_2}{c_0} = d_1 d_2$$

$$f_3 = \frac{c_3}{c_0} = d_1 d_2 d_3$$

$$f_4 = \frac{c_4}{c_0} = d_1 d_2 d_3 d_4$$  \hspace{1cm} (18)

Since $\frac{c_4}{c_3} = d_4 = 1$ \hspace{0.5cm} (C_3 = C_4, for \hspace{0.5cm} \lambda_3 \ll \lambda_4) \hspace{0.5cm} $|$ Eq. (13) becomes as:

$$f_4 = \frac{c_4}{c_0} = d_1 d_2 d_3$$  \hspace{1cm} (19)

When the ventilation rate is the only environmental factor affecting disequilibrium or when it is the dominant one, ventilation rates and the equilibrium factor are obtained by track density measurements only[11].

$$\Lambda_i = V + \lambda_i$$  \hspace{1cm} (20)

The track density of both bare mode and in can mode (with sponge filter) detectors relates the concentration of radon and its daughters as [12];

$$\rho_S = \rho_0 + \rho_1 + \rho_4 \hspace{1cm} \text{In can mode}$$  \hspace{1cm} (21)

$$\rho_S = (K_0 + K_1 f_1 + K_4 f_4) C_0 T$$  \hspace{1cm} (22)

$$f_1 = f_2 = f_3 = f_4 = 1$$ \hspace{0.5cm} $|$ Eq. (22) becomes;

$$\rho_S = K_S C_0 T$$  \hspace{1cm} (23)

where $K_S = K_0 + K_1 + K_4$  \hspace{1cm} (24)
In bare mode \[1,9,13,14\]

\[
\rho_B = \rho_0 + \rho_1 + \rho_4
\]  
(25)

\[
\rho_B = (\bar{K}_0 + \bar{K}_1 f_1 + \bar{K}_4 f_4) \bar{C}_0 T
\]  
(26)

In bare mode \(f_1 \neq f_2 \neq f_3 \neq f_4\) because no equilibrium between the radon and its progenies, but \(\bar{K}_0 = \bar{K}_1 = \bar{K}_4 = K_B\), therefore Eq. (26) becomes:

\[
\rho_B = K_B (1 + f_1 + f_4) \bar{C}_0 T
\]  
(26)

By dividing Eq.(23) on Eq.(26) then;

\[
\frac{\rho_B}{\rho_S} = \frac{K_B}{K_S} (1 + f_1 + f_4) \frac{\bar{C}_0}{c_0}
\]  
(27)

If \(\bar{C}_0 = C_0\)

Eq. (27) becomes;

\[
1 + f_1 + f_4 = K_{SB} \rho_{BS}
\]  
(29)

where

\[
\rho_{BS} = \frac{\rho_B}{\rho_S}
\]

\[
K_{SB} = \frac{K_S}{K_B}
\]  
(30)

From equations 18, 19, 29, we obtain;

\[
1 + d_1 + d_4 d_2 d_3 = K_{SB} \rho_{BS}
\]  
(31)

After rearranging the equations, we obtain;

\[
V^3 + a_2 V^2 + a_1 V + a_0 = 0
\]  
(32)

where

\[
a_2 = (1 + B)\lambda_1 + \lambda_2 + \lambda_3
\]

\[
a_1 = (1 + B)(\lambda_2 + \lambda_3)\lambda_1 + \lambda_2 \lambda_3
\]

\[
a_0 = (1 + 2B)\lambda_1 \lambda_2 \lambda_3
\]

\[
B = \frac{1}{1 - K_{SB} \rho_{BS}}
\]  
(33)

Ventilation rate is the solution of equation (32), obtained by means of standard algebraic procedures [13].
The equilibrium factor is strongly dependent on the ventilation rate; this dependence was expressed by using equations 10, 18 and 20 for radon and 12, 18 and 20 for thoron [9]

\[ F_{Rn} = \frac{\lambda_1}{(\lambda_1 + V)} \left( 0.11 + 0.51 \frac{\lambda_2}{(\lambda_2 + V)} + 0.38 \frac{\lambda_3}{(\lambda_2 + V)(\lambda_3 + V)} \right) \]  

\[ F_{Tn} = \frac{\lambda_1 \lambda_2}{(\lambda_1 + V)(\lambda_2 + V)} \left( 0.91 + 0.09 \frac{\lambda_3}{(\lambda_3 + V)} \right) \]  

(34)  

(35)

Values of the equilibrium factor \( F \), follow from the solution of Eq.(32) combined with Eq.(34) and Eq.

3. Material and Methods

The measuring device is a diffusion cup of plastic 5.5 cm in diameter and 4.5 cm in length equipped with two detectors of LR-115 type II (Kodak path, France) attached with double adhesive tapes at top centre inside and outside the dosimeter. A sponge has been mounted to cover the opening of the cup. The first detector measured \(^{222}\)Rn and its progenies, while the second detector outside the cup (bare detector) record alpha particles produced by radon, thoron and their daughters. The shape of the cup dosimeter is shown in figure (1). The detection system was calibrated at the Environmental Pollution Laboratory in Physics Department university of Basra, for conversion of the track density (track.cm\(^{-2}\)) to activity concentration (Bq.m\(^{-3}\)) [11]. Three experiments were performed for the calibration of the detector, cup with sponge, cup with filter and bare modes using \(^{226}\)Ra (185 kBq) standard source. Table (4) shows the experimental values of calibration factor for LR-115 type II detectors in can and bare mode.

![Figure 1. The indoor radon measurement cup](image)

**Table 4.** The values of calibration factor for LR-115- II detectors

| Mode of exposures | Calibration factor for radon (track.cm\(^{-2}\)/Bq.m\(^{-3}\)) |
|-------------------|---------------------------------------------------------------|
| Sponge mode (\(K_S\)) | 0.020±0.005 |
| Filter mode (\(K_F\)) | 0.021±0.006 |
| Bare mode (\(K_B\)) | 0.029±0.008 |

The dosimeters were distributed inside 34 different indoor locations in selected area in Basra Government in Iraq. After an exposure time of 90 days, the detectors were collected and chemically etched in 2.5N NaOH solution at (60 ± 1) °C for a period of about 90 min in an etching bath to reveal
alpha tracks. The counting of alpha tracks was done using an optical microscope with a magnification of 400X. The background tracks were subtracted from the tracks of exposed detectors and the average tracks were calculated.

4. Results and discussion

The track density, which is the total tracks per unit area of detector, is calculated from the general relation:

$$\rho = \frac{N_{\text{total track}}}{n A_{\text{FOV}}} = \frac{N_{\text{avg}}}{A_{\text{FOV}}}$$

(36)

where \( n \) is the number of fields, \( N_{\text{avg}} \) is the average of tracks numbers and \( A_{\text{FOV}} \) is the area of the field of view. Table (5) represents the results of tracks density ratio between the bare and sponge modes \( \rho_{BS} \) with the calculated values of equilibrium factor of radon and thoron according to the methodology described by Eq.31. It may be recalled that the values \( F \) were calculated from experimental measurements and that \( \rho_{BS} \) values were calculated from measurements and calculations.

| No. | \( \rho_{BS} = \frac{\rho_B}{\rho_S} \) | \( F_{Rn} \) | \( F_{Tn} \) | No. | \( \rho_{BS} = \frac{\rho_B}{\rho_S} \) | \( F_{Rn} \) | \( F_{Tn} \) |
|-----|--------------------------------------|------------|------------|-----|--------------------------------------|------------|------------|
| 1   | 4.22                                 | 0.98       | 0.3794     | 18  | 3.00                                 | 0.37       | 0.0273     |
| 2   | 1.82                                 | 0.03       | 0.0013     | 19  | 4.17                                 | 0.96       | 0.3160     |
| 3   | 2.10                                 | 0.07       | 0.0032     | 20  | 2.11                                 | 0.07       | 0.0033     |
| 4   | 1.58                                 | 0.01       | 0.0004     | 21  | 4.18                                 | 0.96       | 0.3268     |
| 5   | 2.22                                 | 0.09       | 0.0044     | 22  | 2.85                                 | 0.30       | 0.0198     |
| 6   | 2.25                                 | 0.09       | 0.0047     | 23  | 4.17                                 | 0.96       | 0.3160     |
| 7   | 4.00                                 | 0.88       | 0.1949     | 24  | 4.08                                 | 0.91       | 0.2395     |
| 8   | 2.11                                 | 0.07       | 0.0033     | 25  | 4.14                                 | 0.95       | 0.2922     |
| 9   | 1.86                                 | 0.03       | 0.0015     | 26  | 2.92                                 | 0.33       | 0.0230     |
| 10  | 4.08                                 | 0.91       | 0.2395     | 27  | 2.93                                 | 0.34       | 0.0236     |
| 11  | 2.00                                 | 0.05       | 0.0024     | 28  | 2.79                                 | 0.27       | 0.0174     |
| 12  | 3.83                                 | 0.80       | 0.1326     | 29  | 2.73                                 | 0.25       | 0.0154     |
| 13  | 2.33                                 | 0.11       | 0.0059     | 30  | 2.00                                 | 0.05       | 0.0024     |
| 14  | 2.00                                 | 0.05       | 0.0024     | 31  | 2.93                                 | 0.34       | 0.0238     |
| 15  | 2.06                                 | 0.06       | 0.0029     | 32  | 4.17                                 | 0.96       | 0.3160     |
| 16  | 1.75                                 | 0.02       | 0.0010     | 33  | 2.40                                 | 0.13       | 0.0069     |
| 17  | 2.91                                 | 0.33       | 0.0227     | 34  | 2.60                                 | 0.19       | 0.0113     |
The experimental data presented in Table 5 show large variation of $F$ in dwellings, which ranges from 0.01 to 0.98 for radon and from 0.0004 to 0.3794 for thoron. The relationship between $F$ and $\rho_{BS}$ is shown in Figure 2.

![Figure 2. $F_{Rn}$ and $F_{Th}$ related to $\rho_{BS}$ as listed in Table 5](image)

From fitting to the curves in figure 2, we obtain analytical relation for the equilibrium factor as function of the track density ratio in bare and sponge mode;

$$F_{Rn} = a_1 + b_1 \rho_{BS} + ce^{d \rho_{BS}}$$  \hspace{1cm} (37)  

$$F_{Th} = a_2 e^{b_2 \rho_{BS}}$$  \hspace{1cm} (38)

|     | $a_1$     | $b_1$     | $c$     | $d$     | $a_2$     | $b_2$     |
|-----|------------|------------|---------|---------|------------|------------|
|     | -1.70766   | 0.62419    | 3.19876 | -0.92256 | 7.0292*10^{-6} | 2.57099   |

From the fitting function we established a relation for the calculation of the average equilibrium factors written as;

$$\bar{F} = \frac{1}{\rho_{BS}^{max} - \rho_{BS}^{min}} \int_{\rho_{BS}^{min}}^{\rho_{BS}^{max}} F(\rho_{BS}) \, d\rho_{BS}$$  \hspace{1cm} (39)

Using the values of $\rho_{BS}^{min} = 1.58$ and $\rho_{BS}^{max} = 4.2$ (from table 5), one can calculate the average values of equilibrium factor for both radon and thoron in this area and they are;

$$\bar{F}_{Rn} = 0.38 \quad \text{and} \quad \bar{F}_{Th} = 0.05$$

These values are in agreement with ICRP values ($F_{Rn}=0.4$ and $F_{Th} = 0.1$) and many research works [13,8,6,1].
5. Conclusion
In present investigation about the equilibrium factor, theoretical calculations using graphical solutions supported by experimental technique have been determined. It is found that the globally assumed equilibrium factor from UNSCEAR and our experimentally obtained value are in a good agreement. For more accurate estimation of the effective dose, one should measure the F-factor at each site considering all the effective parameters like the ventilation factors. The equilibrium factor was found to be small in some houses due to the very intensive ventilation system in the house.

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