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Calibration Factor for LR-115 Type II Track Detectors for Environmental Radon Measurements

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Abstract—This paper presents the experimental calibration of LR-115 type II plastic track detectors for monitoring environmental radon. The detectors were calibrated using a standard radon chamber and simulating the environmental conditions as normally found in dwellings. The value of the calibration factor was found to be 625 tracks cm−2 d−1 per WL in the BARE mode and 0.116 tracks cm−2 d−1 per Bq m−3 for cup with membrane mode. Results of measurements of radon and its daughters in Bijnor (India) are also presented.

INTRODUCTION

The monitoring of indoor radon levels has acquired great importance from the public health point of view since the early 1980s. During this period the data on high indoor radon levels reported from Sweden and Canada gave alerting signals of carcinogenic effects leading to lung cancer. National surveys of indoor radon levels started in many countries (Abu-Jarad and Al-Jarallah, 1984; Cohen, 1986; Tymen et al., 1986; Wattanikorn et al., 1988; Sohrabi and Solymanian, 1988; Torrie et al., 1988; Tufail et al., 1988; Rannou, 1989; Subba Ramu et al., 1991) soon after the incidental discovery, in December 1984, of the Watras’ house (Lowder, 1989) in eastern Pennsylvania with radon concentrations in the region of 100,000 Bq m−3. Such surveys are essential to understand and to better estimate the risk to human health from radon exposure to sensitive lung tissues (Sevc et al., 1976; Ramachandran et al., 1988; Lowder, 1989). In India also, a few groups are engaged in indoor radon measurements (Khan et al., 1988; Singh, 1989; Subba Ramu et al., 1991).

The α-sensitive plastic track detectors provide a very useful, and less expensive, method for integrated radon measurements (Frank and Benton, 1977; Fleischer et al., 1980). Generally, two plastic track detectors have been used for this purpose (i) the CR-39 detectors (manufactured by Pershore Mouldings Ltd., U.K.) and the LR-115 detectors (manufactured by Kodak Pathé, France and marketed by Dosirad, France).

The CR-39 plastic is more sensitive and records α-particles from almost zero energy to 60 MeV. Because of the extreme sensitivity to α-particles of all energies, this plastic has been extensively employed for radon measurements during the past fifteen years.

However, it has recently been realized that the extreme sensitivity of CR-39 plastic causes problems. It accumulates a much larger number of background tracks during its shelf-life, even when protected by a thin film of plastic on its surface. The signal to background ratio is very low, especially in old CR-39 plastics. The CR-39 plastic is also sensitive to recording the ‘self plating’
radon daughters ($^{218}$Po and $^{214}$Po) which settle on the detector surface along with the aerosols to which they become attached in ambient air. Alpha-particle tracks recorded due to the "self plate-out effect" give spurious track counts and too high results.

Some workers (Khan et al., 1988) have tried to reduce this defect by not counting the small tracks, but this method is subjective and depends upon the etching time and counting criteria employed. Moreover, the etching of CR-39 requires 6–10 h at 70°C in 6N NaOH solution. This is also quite cumbersome when several detectors are to be etched, unless one uses a large etching tank for simultaneous etching of a large number of plastic detectors. Due to these and many other reasons, such as non-uniformity of etching characteristics in different parts of the same sheet and in different batches etc. the use of CR-39 for environmental radon measurements is not advisable, particularly in those cases where accuracy of the quantitative results is particularly important.

The LR-115 type II plastic, on the other hand, is free from these problems. Since it consists of a 12–13 μm thick α-sensitive layer of red-dyed cellulose nitrate plastic deposited on a 100 μm thick non-etchable polyester base, it exhibits (Somogyi, 1986) an energy window (1.9–4.2 MeV) for revealing tracks of α-particles as "through etched holes". All α-particles having energies between these two limits and entering the plastic at an angle greater than 40° ± 5° measured with the detector surface, produce 'through etched holes' when etched for 2 h in 2.5 N NaOH at 60°C. This etching reduces the thickness from 12–13 μm to 5–6 μm and records α-particles with 100% efficiency (Somogyi, 1986). The LR-115 type II plastic is free from the 'self plate-out' effect as it does not record tracks due to self-plating daughters, which emit α-particles of 6.00 MeV ($^{218}$Po) and 7.69 MeV ($^{214}$Po). The etching time for LR-115 type II is only 2 h and the tracks are seen as bright circular holes against a red background which are easily countable at a magnification of >100×. The use of a green filter improves the field of view. Moreover, the 5–6 μm residual thickness of this plastic can be stripped and track counting can be done within seconds using a spark counter (Somogyi et al., 1978). All these advantages make the LR-115 type II plastic more favourable for environmental radon measurements compared to the CR-39 plastic.

The radon concentration, $C$, measured by an α-sensitive plastic detector is related to the track density $\rho$ and the time of exposure $t$ by the formula (Abu-Jarad et al., 1980):

$$\rho = K \cdot C \cdot t$$

where $K$ is the sensitivity factor with a value which depends on the configuration of the detector, viz-a-viz its surroundings, and also on the etching conditions used. Although the value of $K$ can be calculated for different geometries (Fleischer et al., 1980), the calculation is not very straightforward, except in the case of "BARE" detector mode (Abu-Jarad et al., 1980). It is always preferable to use the calibrated value of $K$ obtained from laboratory calibration experiments using a standard radon chamber.

Several workers (Rannou, 1989; Singh et al., 1986; Cheroutie et al., 1988; Subba Ramu et al., 1988; Tommasino, 1989; Osborne, 1989; Ramachandran et al., 1990; Jojo, 1993) have calibrated the LR-115 type II plastic for their cases (see Table 4). It can be seen that different calibration constants have been obtained by different workers, even for the simplest 'BARE' mode of the detector. The reason for this variation may be due to the fact that they used plastic from different batches and also employed different etching times, although all used 2.5 N NaOH solution at 60°C. It is, therefore, necessary to calibrate an identified plastic of a particular batch using a standard source and then to calibrate successive batches of the LR-115 plastic, at least by inter-calibration with the earlier one.

This paper describes the results of calibrating our newly-imported LR-115 type II plastic (manufacturing date Feb., 1993) using the standard radon chamber developed in the Environmental Assessment Division of the Bhabha Atomic Research Center, Bombay, India. The measured values of potential α-particle energy concentration (mWL), radon concentration (Bq m$^{-3}$) in 20 houses in Bijnor city, India are also reported. The effective dose-equivalent received by the lungs of the occupants have also been calculated using a conversion factor of 9 mSV WLM (ICRP-50) and assuming an occupancy factor of 0.67.
EXPERIMENTAL DETAILS

Figure 1 shows a schematic diagram of the system used for calibrating the track detectors. It consists of an exposure chamber, an aerosol generator, a radon gas source, conventional filter paper sampler, radon gas collection chamber and an α-particle counting unit.

The exposure chamber is a wooden box of 0.5 m³ capacity with two inlet and outlet ports and a viewing glass panel. There is an air-tight window for introducing the detectors inside the chamber. Filtered air, aerosols and radon are introduced into the chamber through inlet ports. The residue from any earlier experiment in the chamber is discharged outside the laboratory using an outlet tube. For maintaining uniformity inside the chamber a small fan is incorporated.

The exposure chamber has the following features:

(i) Well-characterized environment with respect to daughter equilibrium, aerosol size, concentration and humidity.
(ii) Accurately known radon concentration (Bq m⁻³) and radon daughter concentration (WL).
(iii) Continuous radon and WL monitoring instrumentation.
(iv) Uniformity of radon concentration within an exposure chamber which permits the simultaneous exposure of various detector configurations.

The aerosol generator is of the La Mer-Sinclair type condensation aerosol generator (Subba Ramu, 1978) which gives a laminar flow of mono-disperse aerosols of di-2-ethylhexylesebacate condensed on NaCl nuclei. Mono-disperse aerosols of 0.2 μm aerodynamic size were obtained by setting the temperature of the re-heater and the boiler. The value of 0.2 μm size was chosen because the activity median aerodynamic diameter (AMAD) value for indoor radon daughters is estimated to be 0.2 μm (Muraleedharan et al., 1986). A concentration of a few thousand particles per cm³ was maintained in these experiments. The small fan inside the chamber maintains a uniform concentration of aerosols, radon and daughters. For aerosols of 0.2 μm used in the experiment the diffusional and deposition losses were minimal. The concentration of aerosol was measured by a small particle counter (Rich, 1955).

![Fig. 1. Schematic diagram of the apparatus used for the calibration. 1. Stirrer; 2. temperature controls; 3. thermostats; 4. platinum wire; 5. nitrogen from CYL-1; 6. nitrogen from CYL-2; 7. filter; 8. radon source; 9. aerosol free air; 10. air-tight window; 11. BARE detector; 12. detector inside cup; 13. BARE on cup; 14. membrane; 15. inlet port; 16. outlet port.]

Radon daughter aerosol chamber
The radon source was a solution of $1.85 \times 10^5$ Bq activity of Ra-226 (in the form of radium nitrate) in 150 ml of 1.0 N HNO$_3$ kept in a flask. Radon emanating from the solution was carried into the chamber through an inlet port by blowing nitrogen above the solution surface. Depending on the flow duration, a specific concentration of radon could be obtained along with the carrier gas flowing at a rate of 1 L min$^{-1}$.

During the course of the experiment the concentration of radon and its daughters was constantly monitored. The individual daughter activity levels were estimated by collecting airborne particles on a millipore filter paper (type AA) having a diameter of 2.5 cm and a pore size of 0.8 μm. A known volume of air from the chamber was sucked in using a vacuum pump at a rate of 10 L/min for 5 min. Measurements of α-particle activity on the filter paper were made using a ZnS (Ag) counter. The α-particle activity levels of the daughter, the concentration of radon and the equilibrium factor were estimated by the α-particle counts with the help of a computer programme (Rangarajan and Datta, 1976) based on the weighted least squares method considering all the radioactive decay at different times.

The radon concentration was estimated using the relation:

$$C_{\text{Rn}} = \frac{RaA (\lambda_A + V)}{\lambda_A}$$

where $RaA$ is the computed Ra A (Bq m$^{-3}$), $\lambda_A$ is the decay constant of Ra A and $V$ is the ventilation rate (h$^{-1}$).

The ventilation rate is computed by the relation:

$$V = \frac{1 - RaB/RaA}{RaB/RaA} \times \lambda_B/(RaB/RaA)$$

where $RaA$ and $RaB$ are the estimated daughter concentrations in Bq m$^{-3}$ and $\lambda_B$ is the decay constant of Ra B in min$^{-1}$.

The WL concentration was estimated using the relation:

$$C_{\text{WL}} = 2.78 \times 10^{-5} (RaA) + 1.37 \times 10^{-4} (RaB) + 1.01 \times 10^{-4} (RaC)$$

where $RaA$, $RaB$ and $RaC$ are the concentrations of radon daughters in Bq m$^{-3}$.

**Procedure**

LR-115 type II plastic track detectors were prepared in three configurations, viz:

(i) `BARE` on card.
(ii) `BARE` on cup.
(iii) Detector inside the cup with membrane.

The (i) and (ii) configurations are used for measuring the potential α-particle energy concentration (PAEC) in WL in the environment. The (iii) configuration is the `radon only` device for measuring the radon concentration in Bq m$^{-3}$. Using (ii) and (iii) together one can find the `equilibrium factor` from the relation:

$$F = \frac{3700 \times C_{\text{WL}}}{C_{\text{Rn}}}$$

where $C_{\text{Rn}}$ is the radon concentration in Bq m$^{-3}$.

In the BARE on card mode a piece (2.5 x 2.5 cm) of the LR-115 type II plastic track detector was fixed on a thick card and in the BARE on cup mode the detector was fixed on the outer slanted surface of the cup having an upper dia. of 7 cm, lower dia. 5.5 cm and height 7 cm. The detectors inside the chamber were exposed in such a way that there was nothing to obstruct the detectors within a hemispherical volume of radius 9.1 cm in front of them. In the cup with membrane mode the detector was fixed on the bottom within the cup. The mouth of the cup was covered with a semipermeable latex membrane. The membrane does not permit the solid daughter products of radon to pass through it and partly reduces the rate of diffusion of radon gas itself. It has been reported that 66% of radon penetrates, but thoron does not enter the cup (Jojo, 1993).
The residual radon and its daughter products, left from an earlier experiment, were flushed out by using a vacuum pump and pouring in the fresh air. Aerosols of size 0.2 μm were introduced into the chamber. The aerosol concentration of 2.7 × 10^4 aerosols/cm^3 was maintained throughout the experiment. For each set of exposures this aerosol concentration was slightly different. Radon gas was pumped into the chamber using nitrogen as carrier gas. Nitrogen was passed over the surface of the flask containing radium solution at a rate of 1 L/min for a known period of time which was determined by the quantity of radon required in the exposure chamber. The LR-115 detectors were introduced inside the exposure chamber in all three modes. The detectors were exposed for a period ranging from a few hours to a few days, depending on the radon concentration, so that a statistically acceptable number of tracks could be obtained on the detectors. Different air filter samples from the exposure chamber were taken at regular intervals for calculating the PAEC (WL) levels and radon concentrations in Bq m^-3. The aerosol concentration was also monitored during the experiment.

The exposed detectors were etched in 2.5 N NaOH solution at 60 ± 1°C for 120 min. The etched detectors were counted using an optical microscope at a magnification of 100 x and the track density (tracks cm^-2) was calculated using a calibrated square marked graticule.

RESULTS AND DISCUSSION

Table 1 gives the PAEC levels of radon daughters in WL and track production rate (tracks cm^-2 d^-1) along with the calibration factor (tracks cm^-2 d^-1 WL) for BARE on card mode. The PAEC (WL) is seen to vary from 0.057 to 0.374 WL and the track production rate from 45 to 185 T cm^-2 d^-1. It is seen that the average calibration factor for LR-115 type II plastic in the BARE on card mode reaches 62.5 T cm^-2 d^-1 WL with a relative SD of 18%. Figure 2 shows the linear relationship between the track production rate and PAEC (WL).

Table 1. Calibration factor for BARE on card mode

<table>
<thead>
<tr>
<th>S no.</th>
<th>Exposure time (h)</th>
<th>PAEC level (WL)</th>
<th>Track production rate (T cm^-2 d^-1)</th>
<th>Calibration factor (T cm^-2 d^-1 WL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>49.4</td>
<td>0.057</td>
<td>45</td>
<td>790</td>
</tr>
<tr>
<td>2</td>
<td>71.0</td>
<td>0.059</td>
<td>46</td>
<td>789</td>
</tr>
<tr>
<td>3</td>
<td>70.3</td>
<td>0.115</td>
<td>70</td>
<td>699</td>
</tr>
<tr>
<td>4</td>
<td>46.0</td>
<td>0.141</td>
<td>83</td>
<td>589</td>
</tr>
<tr>
<td>5</td>
<td>69.5</td>
<td>0.199</td>
<td>124</td>
<td>623</td>
</tr>
<tr>
<td>6</td>
<td>39.5</td>
<td>0.331</td>
<td>161</td>
<td>486</td>
</tr>
<tr>
<td>7</td>
<td>23.3</td>
<td>0.374</td>
<td>185</td>
<td>495</td>
</tr>
</tbody>
</table>

Arithmetic mean, 62.5.
SD, 113.
Relative SD, 18%.

Table 2. Calibration factor for cup with membrane

<table>
<thead>
<tr>
<th>S no.</th>
<th>Exposure time (h)</th>
<th>Radon conc (Bq m^-3)</th>
<th>Track production rate (T cm^-2 d^-1)</th>
<th>Calibration factor (T cm^-2 d^-1 Bq m^-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>71.0</td>
<td>200.95</td>
<td>24</td>
<td>0.119</td>
</tr>
<tr>
<td>2</td>
<td>49.4</td>
<td>308.83</td>
<td>39</td>
<td>0.126</td>
</tr>
<tr>
<td>3</td>
<td>70.3</td>
<td>452.13</td>
<td>43</td>
<td>0.095</td>
</tr>
<tr>
<td>4</td>
<td>46.0</td>
<td>615.64</td>
<td>76</td>
<td>0.123</td>
</tr>
<tr>
<td>5</td>
<td>69.5</td>
<td>977.40</td>
<td>95</td>
<td>0.097</td>
</tr>
<tr>
<td>6</td>
<td>39.5</td>
<td>1653.79</td>
<td>205</td>
<td>0.124</td>
</tr>
<tr>
<td>7</td>
<td>23.3</td>
<td>1981.37</td>
<td>250</td>
<td>0.126</td>
</tr>
</tbody>
</table>

Arithmetic mean, 0.116.
SD, 0.013.
Relative SD, 11%.
Table 2 shows the radon concentration in Bq m$^{-3}$ and the track production rate (T cm$^{-2}$ d$^{-1}$) along with the calibration factor for ‘cup with membrane’ mode. The radon concentration in this case varies from 200.95 to 1981.37 Bq m$^{-3}$ whereas the track production rate varies from 24 to 250 T cm$^{-2}$ d$^{-1}$. The average value of the calibration factor for this mode is 0.116 T cm$^{-2}$ d$^{-1}$/Bq m$^{-3}$ with a relative standard deviation of 11%. Figure 3 represents the linear relationship between the track production rate and the concentration of radon in Bq m$^{-3}$ for this case.

Table 3 gives the PAEC (WL), track production rate and the calibration factor for ‘BARE’ on cup mode. The arithmetic mean of the calibration factor in this case is 570 T cm$^{-2}$ d$^{-1}$/WL with a

<table>
<thead>
<tr>
<th>S no.</th>
<th>Exposure time (h)</th>
<th>PAEC level (WL)</th>
<th>Track production rate (T cm$^{-2}$ d$^{-1}$)</th>
<th>Calibration factor (T cm$^{-2}$ d$^{-1}$/WL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>49.4</td>
<td>0.057</td>
<td>40</td>
<td>702</td>
</tr>
<tr>
<td>2</td>
<td>71.0</td>
<td>0.059</td>
<td>45</td>
<td>763</td>
</tr>
<tr>
<td>3</td>
<td>70.3</td>
<td>0.115</td>
<td>68</td>
<td>591</td>
</tr>
<tr>
<td>4</td>
<td>46.0</td>
<td>0.141</td>
<td>74</td>
<td>525</td>
</tr>
<tr>
<td>5</td>
<td>69.5</td>
<td>0.199</td>
<td>113</td>
<td>568</td>
</tr>
<tr>
<td>6</td>
<td>39.5</td>
<td>0.331</td>
<td>135</td>
<td>408</td>
</tr>
<tr>
<td>7</td>
<td>23.3</td>
<td>0.374</td>
<td>162</td>
<td>433</td>
</tr>
</tbody>
</table>

Arithmetic mean, 570.
SD, 121.
Relative SD, 21%. 

![Linear correlation coefficient = 0.993](image1)

Fig. 2. Calibration curve of LR-115 type II detector in BARE on card mode.

![Linear correlation coefficient = 0.993](image2)

Fig. 3. Calibration curve of LR-115 type II detector in cup with membrane mode.
relative standard deviation of 21%. Figure 4 shows the relationship between the track production rate and the PAEC (WL).

Using the BARE on card mode, measurements were made for indoor radon levels in living and drawing rooms of 20 houses in different localities of Bijnor city during August–October, 1993. The results are shown in Table 5. It is seen from this table that the PAEC varies from 4.62 to 8.69 mWL with a geometric mean value of 6.34 mWL while the radon concentration varies from 39.75 to 74.77 Bq m$^{-3}$ with a geometric mean value of 54.52 Bq m$^{-3}$. These values of radon concentration are much less than values which give rise to concern i.e. 150 Bq m$^{-3}$ (McLaughlin, 1989) and no intervention is required. The intervention, or action level as recommended by ICRP-65 is 200 Bq m$^{-3}$.

CONCLUSIONS

From the calibration experiment the following conclusions can be made:

(i) The PAEC (WL) and radon concentrations used in the experiment are more than those normally found in the environment, except in some mines. However, the calibration results show that the relation is linear and hence the calibration graph can be extrapolated and also used for smaller concentrations. However, it is essential to expose the detector for a longer time (2–3 months) so that a statistically significant number of tracks may be obtained. Further, a large area of the exposed detector should be counted.
Table 5. Concentration of radon and its daughter products in different localities of Bijnor, India

<table>
<thead>
<tr>
<th>Locality</th>
<th>Detector code</th>
<th>Track production rate (T cm$^{-2}$ d$^{-1}$)</th>
<th>PAEC (mWL)</th>
<th>Conc. of radon (Bq m$^{-3}$)</th>
<th>Effective dose-equi. (mSv;yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qazi Para</td>
<td>B1</td>
<td>4.31</td>
<td>6.90</td>
<td>59.37</td>
<td>2.14</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>5.32</td>
<td>8.51</td>
<td>73.23</td>
<td>2.64</td>
</tr>
<tr>
<td></td>
<td>B3</td>
<td>3.35</td>
<td>5.26</td>
<td>46.12</td>
<td>1.67</td>
</tr>
<tr>
<td></td>
<td>B4</td>
<td>4.11</td>
<td>6.58</td>
<td>56.62</td>
<td>2.04</td>
</tr>
<tr>
<td></td>
<td>B5</td>
<td>4.51</td>
<td>7.22</td>
<td>62.13</td>
<td>2.24</td>
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<tr>
<td>Mirdghan</td>
<td>B6</td>
<td>2.89</td>
<td>4.62</td>
<td>39.75</td>
<td>1.44</td>
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<tr>
<td></td>
<td>B7</td>
<td>3.85</td>
<td>6.16</td>
<td>53.00</td>
<td>1.91</td>
</tr>
<tr>
<td></td>
<td>B8</td>
<td>3.52</td>
<td>5.63</td>
<td>48.44</td>
<td>1.75</td>
</tr>
<tr>
<td></td>
<td>B9</td>
<td>4.20</td>
<td>6.72</td>
<td>57.82</td>
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<td>3.56</td>
<td>5.70</td>
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<td>Chasherin</td>
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<td>5.43</td>
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<td>74.77</td>
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<td></td>
<td>B12</td>
<td>3.91</td>
<td>6.26</td>
<td>53.87</td>
<td>1.95</td>
</tr>
<tr>
<td></td>
<td>B13</td>
<td>3.29</td>
<td>5.26</td>
<td>45.26</td>
<td>1.63</td>
</tr>
<tr>
<td></td>
<td>B14</td>
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<td>4.31</td>
<td>6.61</td>
<td>56.88</td>
<td>2.05</td>
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<tr>
<td>Main Bazar</td>
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<td>4.92</td>
<td>7.87</td>
<td>67.72</td>
<td>2.45</td>
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<td>B17</td>
<td>5.25</td>
<td>8.40</td>
<td>72.28</td>
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<td>B18</td>
<td>2.97</td>
<td>4.73</td>
<td>40.87</td>
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<td>B19</td>
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<td>6.14</td>
<td>52.83</td>
<td>1.91</td>
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<td>B20</td>
<td>3.39</td>
<td>5.42</td>
<td>46.64</td>
<td>1.68</td>
</tr>
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</table>

Geometric mean 6.34 54.52 1.97
SD 1.20 10.36 0.37
Relative SD 19% 19% 19%

(ii) The calibration factor for a BARE detector on card is found to be 625 T cm$^{-2}$ d$^{-1}$/WL with a relative SD of 18%. The calibration factor for a BARE detector on cup is 570 T cm$^{-2}$ d$^{-1}$/WL with a relative SD of 21%. These two values are very close and within one SD.

(iii) The calibration factor for a detector inside a cup with a membrane is found to be 0.116 T cm$^{-2}$ d$^{-1}$/per (Bq m$^{-3}$) for radon only with a relative standard deviation of 11%.

(iv) It is seen that the values of calibration factor for a LR-115 detector are slightly more than those reported by Ramachandran et al. (1980). This difference may be due to use of a different manufacturing batch and also due to differences in etching conditions. Hence, it is desirable to have detectors from each batch calibrated before using them for environmental radon measurements.

(v) The values of radon concentrations in typical ground floor rooms of Bijnor city are much less than those levels causing concern (150 Bq m$^{-3}$).

REFERENCES


Radium Concentration and Radon Exhalation Measurements Using LR-115 Type II Plastic Track Detectors

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Abstract The "Track-Etch" technique using LR-115 type II plastic track detectors has been employed for measuring the radium content and radon exhalation rates of different types of building materials. Among the eight materials studied it was found that fine aggregates (Badarpur) show the greatest radon exhalation, whereas portland cement produces minimum values of radon exhalation. Experimentally-measured values of the "effective radium content" (in Bq kg⁻¹) their "mass exhalation" rates (in Bq kg⁻¹ d⁻¹) and "surface exhalation" rates (in Bq m⁻² d⁻¹) are reported.

INTRODUCTION

Inhalation of ²²²Rn and its daughter products, especially ²¹⁸Po and ²¹⁴Po attached to aerosols present in ambient air, constitute a significant radioactive hazard to human lungs (Clement et al., 1984; Steinhauser, 1988). The concentration of radon and its daughters may reach levels of great concern for public health if its value is greater than 150 Bq m⁻³ (McLaughlin, 1989) in closed spaces, such as poorly ventilated houses, large buildings and mines. Radon appears mainly by diffusion processes from the point of origin following α-decay of ²²⁶Ra in underground soil and building materials used in the construction of floors, walls and ceilings for example.

A study of radon exhalation rates from different building materials is important for understanding the relative contributions of individual materials to the total radon content found inside a room. Such a study has been carried out in our laboratory in a series of parallel measurements of radon activity produced inside eight sealed glass cylinders having different building materials. The α-activity measurements were made using BARE LR-115 type II plastic track detectors.

EXPERIMENTAL DETAILS

The experimental arrangement used is shown in Fig. 1. It is basically a modified version of the so-called "can technique" first proposed by Alter and Price (1974) and later employed by many workers (Somogyi, 1986; Somogyi et al., 1986; Karamdoust et al., 1988). It may be called the "radon-α method" for radium determination (Somogyi, 1986). The glass cylinder used had a height of 30 cm and diameter of 10 cm. Equal amounts of completely dried building materials, generally used in Northern India; viz coarse aggregate (Badarpur) fine sand, portland cement, fly ash, coal powder and coal slag were kept at the bottom of identical cylinders. The mass of the material taken was 0.5 kg in each case, except coal powder for which it was 0.3 kg. This was necessitated by
considering keeping the height, \( h \) above the sample surface sufficiently large (19–25 cm) and nearly the same in all cases so that direct \( \alpha \)-particles emitted by the building materials would not reach the detector. The LR-115 type II detector was fixed at the centre of the lid on its inner side, as shown. Initially the glass lid, without a detector, was fixed tightly on the mouth of the cylinder by using “tevicol” adhesive. The enclosure was left for 1 month so as to acquire an equilibrium concentration of radon gas being released by the building materials. After this time, the glass lids were replaced quickly by flat covers having LR-115 detectors (1.5 x 1.5 cm) in the centre, and sealed again. The detectors were open to record \( \alpha \)-particles from the decay of radon and its daughters that accumulated in the air. An exposure time \( T \) of 78 days was employed in this investigation. Since the radius of the cylinder was 5 cm, the daughters plating out on the cylindrical walls did not produce tracks in the LR-115 detector which has an effective critical angle \( \theta_c = 40 \pm 5 \) deg for through-etched-hole formation (Somogyi, 1986).

After exposure the detectors were removed and etched in 2.5 NaOH solution at 60°C for 2 h and the through-etched-holes produced by the \( \alpha \)-particles were counted using an optical microscope at a magnification of 100 x. The relative track density obtained in the detectors from different cylinders gave qualitative information on the radon exhalation from different building materials. The quantitative values of “effective radium content” of the sample (Bq kg\(^{-1}\)), their “mass exhalation” rates (Bq kg\(^{-1}\) d\(^{-1}\)) and the “surface exhalation” rates (Bq m\(^{-2}\) d\(^{-1}\)) for radon were determined from the formulae developed in sequence.

**THEORETICAL CONSIDERATIONS**

Since the half-life of \(^{226}\)Ra is 1620 y and that of \(^{222}\)Rn is 3.82 days, it is reasonable to assume that an effective equilibrium (about 98%) for radium–radon members of the decay series is reached in by about 3 weeks time. Once the radioactive equilibrium is established, one may use the radon \( \alpha \) analysis for the determination of the steady-state activity concentration of radium.
For the wide (10 cm dia) cylinders in this experiment, the LR-115 type II plastic track detectors behave as "BARE" detectors. For the "BARE" detectors, the track density $p$ (in tracks cm$^{-2}$) is related to the radon activity concentration $C_{\text{Rn}}$ (in Bq cm$^{-3}$) and the exposure time $T$ by the formula:

$$p = K \cdot C_{\text{Rn}} \cdot T$$  \hspace{1cm} (1)

where $K$ is the constant of proportionality, referred to as the sensitivity factor, in tracks cm$^{-2}$s$^{-1}$ (Bq cm$^{-3}$) units.

Since the LR-115 type II plastic track detectors have an "energy window" of 1.9-4.2 MeV for the production of through-etched-holes, hence taking the air in front of the detector as "thick source", its sensitivity factor should be given by:

$$K = \frac{1}{\theta_{c}} (R_{\text{max}} - R_{\text{min}}) \cos^{2} \theta_{c}$$  \hspace{1cm} (2)

where $R_{\text{max}}$ is the range of 4.2 MeV $\alpha$-particles, $R_{\text{min}}$ is the range of 1.9 MeV $\alpha$-particles in air and $\theta_{c}$ is the average value of critical angle for the plastic corresponding to these energies.

Using the well known range-energy formula for $\alpha$-particles

$$R_{\text{air}} \text{(in cm)} = 0.322(E_{\alpha} \text{in MeV})^{1.5}$$  \hspace{1cm} (3)

and the average critical angle $\theta_{c} = 40$ deg, the sensitivity factor for the plastic track detector is 0.0245 tracks cm$^{-2}$d$^{-1}$ per (Bq cm$^{-3}$).

The value of radon activity concentration $C_{\text{Rn}}$ (in Bq cm$^{-3}$) can be obtained from the expression:

$$C_{\text{Rn}} = \frac{p}{K \cdot T}$$  \hspace{1cm} (4)

where $K$ is now 0.0245 tracks cm$^{-2}$d$^{-1}$ per (Bq cm$^{-3}$) and $T$ is the total time of exposure in days. Here $p$ is the background-corrected track density (tracks cm$^{-2}$) of the through-etched-holes in the LR-115 type II plastic track detector. It is necessary that, for this value of $K$, the etching is carried out to reduce the thickness of the LR-115 type II detector to about 5 $\mu$m (Somogyi, 1986), which is obtained by 2 h etching of the detector in 2.5N NaOH solution at 60°C.

Referring to Fig. 1, which shows the experimental arrangement for measuring effective radium (i.e. radium in radio active equilibrium with the measured radon released from the sample) the activity concentration of radon begins to increase with time $T_{e}$ after closing the cylinder, according to the relation:

$$C_{\text{Rn}} = C_{\text{Ra}} \left(1 - e^{-\lambda_{\text{Ra}} T_{e}}\right)$$  \hspace{1cm} (5)

where $C_{\text{Ra}}$ is the effective radium content of the sample. Since the plastic track detector measures the time-integrated value of the above expression, i.e. the total number of alpha disintegrations in unit volume of the cylinder with a sensitivity $K$ during the exposure time $T$, hence the track density observed is given by:

$$p = K \cdot C_{\text{Ra}} \cdot T_{e}$$  \hspace{1cm} (6)

or

$$p = k \cdot C_{\text{Ra}} \cdot \left[T - \lambda_{\text{Ra}} (1 - e(-\lambda_{\text{Ra}} T_{e}))\right]$$  \hspace{1cm} (7)

where $T_{e}$ denotes, by definition, the effective exposure time given by:

$$T_{e} = \left[T - \lambda_{\text{Ra}} (1 - e(-\lambda_{\text{Ra}} T))\right].$$  \hspace{1cm} (8)

In our case, since the actual exposure time $T$ is 78 days, the effective exposure time $T_{e} = 78.487$ days.

Referring to Fig. 1 it is clear that the "effective radium content" of the solid sample can be calculated from the formula:

$$C_{\text{Ra}} \text{(Bq kg$^{-1}$)} = \left(\frac{p}{K \cdot T_{e}}\right) \left(\frac{h \cdot A}{M}\right)$$  \hspace{1cm} (9)
where $M$ is the mass of the solid sample in kg, $A$ is the area of the cross-section of the cylinder in m$^2$, $h$ is the distance between the detector and the top of the solid sample in m.

The mass exhalation rate of the sample for the release of the radon can be calculated from:

$$C_{Rn}(\text{Bq kg}^{-1}\text{d}^{-1}) = C_{Ra} \frac{1}{Rn} \frac{A}{T_e}.$$  \hspace{1cm} (10)

The "surface exhalation rate" of the sample for the release of radon will be given by:

$$C_{Rn}(\text{Bq m}^{-2}\text{d}^{-1}) = C_{Ra} \frac{M}{Rn} T_e A.$$  \hspace{1cm} (11)

**RESULTS AND CONCLUSIONS**

Table 1 presents the background-corrected track density and also the calculated values of the "effective radium content" of eight building materials under study. Table 2 shows the mass exhalation rate and surface exhalation rate of different building materials.

### Table 1. Track density data and effective radium content of different building materials

<table>
<thead>
<tr>
<th>Building material</th>
<th>Detector code No.</th>
<th>Distance $h$ (m)</th>
<th>Mass $M$ of sample (kg)</th>
<th>Track density (tracks cm$^{-2}$)</th>
<th>Effective radium content (Bq kg$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse aggregate</td>
<td>21</td>
<td>0.190</td>
<td>0.5</td>
<td>385</td>
<td>0.647 ± 0.033</td>
</tr>
<tr>
<td>Fine aggregate (Badarpur)</td>
<td>26</td>
<td>0.215</td>
<td>0.5</td>
<td>1650</td>
<td>3.138 ± 0.770</td>
</tr>
<tr>
<td>Fine sand (silver white)</td>
<td>24</td>
<td>0.200</td>
<td>0.5</td>
<td>540</td>
<td>0.955 ± 0.041</td>
</tr>
<tr>
<td>Portland cement</td>
<td>20</td>
<td>0.190</td>
<td>0.5</td>
<td>172</td>
<td>0.289 ± 0.022</td>
</tr>
<tr>
<td>Fly ash (HTPS)</td>
<td>19</td>
<td>0.205</td>
<td>0.5</td>
<td>661</td>
<td>1.199 ± 0.047</td>
</tr>
<tr>
<td>Coal powder (PTPS)</td>
<td>22</td>
<td>0.250</td>
<td>0.3</td>
<td>689</td>
<td>2.539 ± 0.097</td>
</tr>
<tr>
<td>Fly ash (PTPS)</td>
<td>23</td>
<td>0.215</td>
<td>0.5</td>
<td>268</td>
<td>0.509 ± 0.031</td>
</tr>
<tr>
<td>Coal slag (PTPS)</td>
<td>25</td>
<td>0.250</td>
<td>0.5</td>
<td>253</td>
<td>0.559 ± 0.035</td>
</tr>
</tbody>
</table>

*HTPS, Harduaganj Thermal Power Station, Aligarh.*

*PTPS, Panki Thermal Power Station, Kanpur.*

### Table 2. Mass exhalation rate and surface exhalation rate of different building materials

<table>
<thead>
<tr>
<th>Building materials</th>
<th>Detector code no.</th>
<th>Mass exhalation (Bq kg$^{-1}$d$^{-1}$) $\times 10^5$</th>
<th>Surface exhalation (Bq m$^{-2}$d$^{-1}$) $\times 10^6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse aggregate</td>
<td>21</td>
<td>5.85 ± 0.30</td>
<td>3.72 ± 0.19</td>
</tr>
<tr>
<td>Fine aggregate</td>
<td>26</td>
<td>28.33 ± 0.68</td>
<td>18.03 ± 0.44</td>
</tr>
<tr>
<td>Fine sand (silver white)</td>
<td>24</td>
<td>8.62 ± 0.37</td>
<td>5.49 ± 0.24</td>
</tr>
<tr>
<td>Portland cement</td>
<td>20</td>
<td>2.61 ± 0.20</td>
<td>1.66 ± 0.13</td>
</tr>
<tr>
<td>Fly ash (HTPS)</td>
<td>19</td>
<td>10.82 ± 0.42</td>
<td>6.89 ± 0.27</td>
</tr>
<tr>
<td>Coal powder (PTPS)</td>
<td>22</td>
<td>22.92 ± 0.87</td>
<td>8.75 ± 0.33</td>
</tr>
<tr>
<td>Fly ash (PTPS)</td>
<td>23</td>
<td>4.59 ± 0.28</td>
<td>2.92 ± 0.18</td>
</tr>
<tr>
<td>Coal slag (PTPS)</td>
<td>25</td>
<td>5.05 ± 0.32</td>
<td>3.21 ± 0.20</td>
</tr>
</tbody>
</table>

*HTPS, Harduaganj Thermal Power Station, Aligarh.*

*PTPS, Panki Thermal Power Station, Kanpur.*
exhalation rates and the surface exhalation rates for radon. It is evident from Table 1 that the effective radium contents for building materials are quite low and vary between 0.289 and 3.138 Bq kg\(^{-1}\). The effective radium content is maximum for fine aggregate (Badarpur) and minimum for portland cement. It is seen from Table 2 that fine aggregate exhibits the highest exhalation rates (28.33 x 10\(^8\) and 18.03 x 10\(^6\) Bq m\(^{-2}\) d\(^{-1}\)) while the portland cement exhibits the lowest exhalation rates (2.61 x 10\(^8\) and 1.66 x 10\(^6\) Bq m\(^{-2}\) d\(^{-1}\)).

It is further evident from Table 2 that fly ash samples collected from two different places exhibit different mass exhalation and surface exhalation rates. The radon exhalation rates from coal powder are higher than from its by-product, fly ash. The same pattern has been observed by Karamdoust \textit{et al.} (1988). This effect may be due to the large surface available for exhalation of radon in larger particles than in powder.

**REFERENCES**


Measurement of Alpha Activity of Indian Chewing Tobacco Samples Using Track Etch Technique

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Abstract: Alpha activity produced by eight different brands of chewing tobaccos have been measured using LR-115 type II plastic detector in the sandwiched pellet technique. Maximum value of alpha activity, 9.43 tracks cm\(^{-2}\) d\(^{-1}\) has been found in the raw tobacco leaves (Sample No. 8) while the minimum value 0.84 tracks cm\(^{-2}\) d\(^{-1}\) was shown by Sample No. 1. Other brands showed intermediate values which are also reported in this paper.

Introduction

India is the third largest producer of tobacco. About 550 million Kg of tobacco is produced in India annually. Snuff and chewing tobaccos account for 30 percent of the total consumption of tobacco. The habit of chewing tobacco is in vogue in Indian youths and even in adolescents. These days, many different brands of flavoured tobaccos have flooded the market in attractive and shining pouches, with the name of ‘Gutka’ or ‘Zarda’ bearing different numbers indicating their ‘kicking power’. Unfortunately, young men and boys consume these tobaccos regularly out of fashion without bothering about the harmful effects. In fact it is a direct source of intake of radioactivity to the inner organs of the human body. The alpha radioactivity of the tobacco produces damaging effects to the living tissues in the mouth, throat and the bladder sometimes leading to the cancerous effects (Eisler, 1964; Martel, 1975).

Tobacco has been found to contain significant amount of a number of radioactive elements such as \(^{210}\)Po, \(^{210}\)Pb, \(^{40}\)K, \(^{226}\)Ra, \(^{238}\)U etc. (Martel, 1974). According to Dr. Sharad Vaid, Chairman of National Organization for Tobacco Eradication, some 5,500 children below 15 years of age consume tobacco every day and eight lakh deaths occur due to tobacco every year (as reported in Times of India, 10 February 1994). Data on alpha activity of the tobaccos will be useful in estimating these harmful effects at least qualitatively.

Experimental Details

Eight different popular brands of tobaccos were purchased from the local market. These fine tobacco leaves were completely dried under an infrared lamp, ground and sieved through 100 mesh separately. Equal amount (150 mg) of each sample powder was mixed thoroughly with 150 mg of methyl cellulose which served as binding agent for making pellets. This mixture was transformed into pellets of diameter 1.3 cm and thickness ~ 2 mm, using a hand pressed pellet making machine. For the measurement of alpha activity each pellet was sandwiched between two circular LR-115 type II plastic track detectors. To make a perfect contact between the surface of the pellet and the detector, each sandwiched pellet was wrapped with cello–tape. The detectors were irradiated in contact for recording the alpha particles from the tobacco samples. After an exposure period of 74 days the detectors were chemically etched in 2.5 N NaOH at 60°C for 2 hours to reveal the latent tracks produced by alpha particles. Thereafter, the detectors were washed in running water and dried. The etched detectors were counted under an optical microscope at a magnification of 100x for finding the track density. Entire area of 1.3 cm\(^2\) was counted. Counting was done on both the pieces and the average track density was obtained. Background track density was calculated before starting the experiment and found to be 33 tracks cm\(^{-2}\). Corrected track density was obtained after subtracting the background in each case.

<table>
<thead>
<tr>
<th>Tobacco Brand Sample</th>
<th>Corrected Track Density (track cm(^{-2}))</th>
<th>Alpha Activity (tracks cm(^{-2}) d(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample No. 1</td>
<td>62</td>
<td>0.84 ± 0.11</td>
</tr>
<tr>
<td>Sample No. 2</td>
<td>65</td>
<td>0.88 ± 0.11</td>
</tr>
<tr>
<td>Sample No. 3</td>
<td>103</td>
<td>1.39 ± 0.14</td>
</tr>
<tr>
<td>Sample No. 4</td>
<td>126</td>
<td>1.70 ± 0.15</td>
</tr>
<tr>
<td>Sample No. 5</td>
<td>132</td>
<td>1.78 ± 0.16</td>
</tr>
<tr>
<td>Sample No. 6</td>
<td>150</td>
<td>2.03 ± 0.17</td>
</tr>
<tr>
<td>Sample No. 7</td>
<td>168</td>
<td>2.27 ± 0.18</td>
</tr>
<tr>
<td>Sample No. 8</td>
<td>698</td>
<td>9.43 ± 0.36</td>
</tr>
</tbody>
</table>
Results and Discussion

Table 1 shows the alpha activity produced by different brands of samples of tobaccos. It is seen from Table 1 that Sample No. 1 produces the least activity while the Sample No. 8 produces the highest alpha activity. Sample No. 8 produces 11.23 times more alpha activity than Sample No. 1. The tobaccos producing increasing order of alpha activity are Sample No. 1, 0.84; Sample No. 2, 0.88; Sample No. 3, 1.39; Sample No. 4, 1.70; Sample No. 5, 1.78; Sample No. 6, 2.03; Sample No. 7, 2.27 and Sample No. 8, 9.43 tracks cm$^{-2}$d$^{-1}$. This difference in alpha activity may be due to the difference in the uranium and radium content of the soil where the tobacco leaves are grown. Further, the ingredients of chewing tobaccos like aromatic spices and saffron may contain different concentration of alpha producing elements. The alpha activity is not solely due to uranium alphas but also due to alpha particles emitted by different members of the uranium–radium series.

References


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Note: The authors have stated that “there is no procedure available for finding the sensitivity factor for this geometry. Hence the alpha activity in terms of track density per day has been reported for comparison purpose.”
TRACE QUANTITIES OF URANIUM IN SOME INDIAN CHEWING TOBACCOS AS DETERMINED BY FISSION TRACK ANALYSIS

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The sandwiched pellet technique using Makrofol-E plastic track detectors has been employed to determine trace quantities of uranium in nine brands of flavored chewing tobaccos consumed by the Indian population. In this technique the nuclear reaction, $^{235}\text{U}(n,f)$, is used for the quantitative estimation of uranium. The maximum value of uranium (1.88 ppm) has been found in raw tobacco leaves (Surti), while the minimum (0.13 ppm) in Tulsi (Double Zero brand). Other seven brands showed intermediate values of U-contents which are also reported in this paper. These values are compared with the U-contents reported in the literature for other forms of tobaccos.

INTRODUCTION

Uranium is a ubiquitous element in nature. It is also found in trace quantity in all the materials we use or eat. Since uranium is a radioactive, toxic element, its **

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presence in edible materials or foodstuffs consumed by humans may affect the human health.

As part of an ongoing project on uranium assessment in solids using SSNTD technique\textsuperscript{1-4}, we endeavor to find uranium contents of chewing tobaccos used by Indians. The habit of chewing tobaccos is in vogue in the Indian subcontinent and other South-Asian countries. These days, many different brands of flavored tobaccos have flooded the market in attractive and shining packages, with the name of 'Gutkha' or 'Zarda', bearing different numbers, indicating their 'kicking power'. Unfortunately, young men and boys consume these tobaccos regularly, out of fashion without bothering about their harmful effects. In fact, it is a direct source of intake of radioactivity to the inner organs of the human body. The $\alpha$-radioactivity of the tobacco produces damaging effects to tissues in the mouth, throat and the bladder, sometimes leading to carcinogenic effects. A knowledge of the uranium content of tobaccos will be useful in estimating these harmful effects at least qualitatively.

**EXPERIMENTAL**

Nine different popular brands of chewing tobaccos (Table 1) were purchased from the local market. These tobacco leaves were completely dried under an infrared lamp, ground and sieved through 100 mesh separately. Equal amounts (150 mg) of each sample powder were mixed thoroughly with 150 mg of methyl cellulose, which served as a uranium-free binding agent for making pellets. This mixture was transformed into pellets of 1.3 cm diameter and 2 mm thickness, using a hand-pressed pellet making
TABLE 1
Uranium content of various brands of Indian chewing tobaccos commercially available in India

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Tobacco brand, Name/No.</th>
<th>Average track density, track cm$^{-2}$</th>
<th>U-content, ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Tulsi (00)</td>
<td>4333</td>
<td>0.13±0.08</td>
</tr>
<tr>
<td>2.</td>
<td>Tulsi (000)</td>
<td>6056</td>
<td>0.18±0.04</td>
</tr>
<tr>
<td>3.</td>
<td>Ratna Chhap (64)</td>
<td>6692</td>
<td>0.20±0.03</td>
</tr>
<tr>
<td>4.</td>
<td>Baba (160)</td>
<td>8353</td>
<td>0.25±0.06</td>
</tr>
<tr>
<td>5.</td>
<td>Rashmi Zarda (95)</td>
<td>8844</td>
<td>0.26±0.13</td>
</tr>
<tr>
<td>6.</td>
<td>Baba (120)</td>
<td>11175</td>
<td>0.33±0.20</td>
</tr>
<tr>
<td>7.</td>
<td>Ratna Chhap (300)</td>
<td>14036</td>
<td>0.42±0.10</td>
</tr>
<tr>
<td>8.</td>
<td>Kapoori</td>
<td>43647</td>
<td>1.30±0.70</td>
</tr>
<tr>
<td>9.</td>
<td>Surti</td>
<td>62802</td>
<td>1.88±0.76</td>
</tr>
</tbody>
</table>

Machine. A similar method was adopted for making pellets of a standard glass containing 0.77 ppm of uranium by weight$^5$, which served as standard for the relative method.

Makrofol-E plastic (manufactured by Bayer A.G. Leverkusen, Germany) was used as track detector for fission fragments. This plastic was cut into circular pieces of 1.3 cm diameter, coded with certain numbers, and washed with 3M HNO$_3$ solution for removing surface contamination of the detectors. The pellets of different tobacco samples and the standard glass were sandwiched in between two such pieces of plastic track detectors. The sandwiched samples were kept one over the other in an aluminium container (length 5.3 cm and diameter 1.5 cm). This tight assembly was sent for thermal neutron irradi-
ation in the APSARA reactor at Bhabha Atomic Research
Centre, Bombay (India) by a thermal neutron fluence of
about 5.4×10^{16} \text{ cm}^{-2}.

After irradiation, the detectors were separated from
the samples and etched in 6N NaOH solution at 60 °C for
60 min, for revealing the tracks of fission fragments.
Thereafter, the detector pieces were washed in running
water and dried under an infrared lamp. The etched
tracks of fission fragments produced in the \text{U(n,f)} re-
action were observed and counted using an Olympus (Ja-
pan) binocular research microscope fitted with a cali-
brated square marked graticule covering a field area of
9×10^{-4} \text{ cm}^2 at a magnification of 280X.

The uranium content was calculated from the expres-
sion\textsuperscript{6}:

\[
U_x = U_s \cdot \frac{I_s}{I_x} \cdot \frac{R_s}{R_x} \cdot \frac{x}{s}
\]

where \(x\) and \(s\) stand for unknown and the standard; \(U\), \(I\),
\(R\) and \(s\) stand for uranium concentration, isotopic abun-
dance ratio of \(^{235}U/^{238}U\), track density and range of fis-
sion fragments.

The value of \(I_s/I_x\) is unity, which is a very reason-
able assumption. The factor \(R_s/R_x\) which has been calcu-
lated by us to be 1.23 from the \(R_z/R_x\) versus \(Z\) plot\textsuperscript{6}.
Earlier workers\textsuperscript{7-8} have taken this factor also to be
equal to 1. The negligence of this factor may, however,
cause significant errors in the determination of trace
quantities of uranium when unknown and known samples are
appreciably different from each other in their atomic
numbers. In our case, the known standard was glass (av-
average \(Z = 14\)) and the unknown was tobacco (average
\(Z = 6\)).
RESULTS AND DISCUSSION

The observed track density data and U-contents of the respective tobaccos are shown in Table 1. These results are also depicted in the bar diagram in Fig. 1.

The average track density from two surfaces of tobacco pellets were found to lie between 4,333 tracks cm$^{-2}$ for the Tulsi brand (No. Double Zero) and 62,802 tracks cm$^{-2}$ for the raw tobacco leaves (Surti). For the standard glass pellet, the average track density was 31,689 tracks cm$^{-2}$ in our case. Here it must be mentioned that a few fields which showed many clusters (not countable) were completely ignored and therefore the actual U-contents may be even higher than those reported by us here.

The different brands under study are seen to have U-contents lying between 0.13 ppm and 1.88 ppm. The minimum value is found for the Tulsi brand (No. Double Zero), while the maximum for the raw tobacco leaves (Surti). Although no reports are known to us for U-contents of chewing tobaccos, the U-content of tobaccos from dif-
different sources such as cigarette (0.037-0.120 ppm), Snuff (7.4-19.1 ppm), Bidi tobacco (0.13-0.23 ppm) and Chhutta (0.16-0.37 ppm) have been reported by certain workers.

The minimum and maximum reported U-contents in tobaccos from different sources, including the present results, are displayed in Fig. 2. It is seen that the chewing tobaccos have maximum uranium contents and therefore are most dangerous from the point of view of causing carcinogenic effects inside the mouth, gums, throat, etc.

The authors express their thanks to the Department Atomic Energy, Government of India, for financial support of the project 27/1/91-G.

REFERENCES


LEVELS OF URANIUM IN WATERS FROM SOME INDIAN CITIES DETERMINED BY FISSION TRACK ANALYSIS

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(Received 8 May 1996)

Abstract—This paper describes the results of measurements on the traces of uranium found in 24 water samples collected from various sources in four important cities of Uttar Pradesh (India). The sources of water samples were municipal taps, private hand pumps, jet pumps and natural rivers, etc. Melinex-O plastic sheets of thickness ~ 100 microns were used as detectors for the registration of fission tracks produced in the $^{235}$U(n,f) reactions. In the case of treated drinking water samples collected from taps supplied by the water works departments of various cities (basic sources for these samples being tube-wells, dams and rivers in different cities as specifically indicated in the paper), the values of uranium concentrations were found to lie between 0.87 ± 0.01 and 11.36 ± 0.34 µg/l. For the untreated water samples collected from private jet pumps and hand pumps, the U-contents were found to vary from 2.02 ± 0.03 to 9.07 ± 0.10 µg/l. The levels of uranium concentration in untreated river water samples of various cities collected directly from the river streams were found to range from 0.92 ± 0.01 to 5.37 ± 0.06 µg/l. The average uranium intake resulting from the drinking tap waters in these cities has also been calculated. They are found to be much less than the maximum permissible limit of 40 mg/day in every case reported in this paper. Copyright © 1996 Elsevier Science Ltd

1. INTRODUCTION

Uranium is the heaviest naturally occurring element present in water in trace quantities. In general, it is difficult to directly analyze such small quantities of uranium in water by routine chemical means. However, the fission track registration technique is easier, less expensive and equally accurate compared to many other prevalent methods (Fisher, 1975), provided one has access to a nuclear reactor irradiation facility.

Uranium is present in almost everything in our natural surroundings in varying proportions. For example, the average uranium concentration in the Earth's crust has been reported to be $4 \times 10^{-7}$% (or 4 ppm) by weight (Hursh and Spoor, 1973) while in the phosphate rocks its value may be as high as $1.2 \times 10^{-6}$% (or 120 ppm) by weight (Rossler et al., 1979). Nearly one hundred mineral species possess almost 1% (or 10,000 ppm) of uranium by weight, while a few ores may contain uranium to the extent of 40-60% (or 400,000-600,000 ppm). Uranium from these rocks and minerals leaches out and mixes with water. Consequently uranium is found in small quantities in dissolved and suspended particulate forms in water—be it surface water (river water) or underground water (i.e. drinking water either from tube-wells, jet pumps, hand pumps or taps supplied after treatment by water works departments in the cities). In the case of surface water, the run-off fertilizers from fields also cause changes in its uranium contents.

The presence of uranium in underground and surface water is due to its natural occurrence and also due to man-made activities like mining and milling of uranium rocks, viz. granites, lignites, monazite sands and minerals such as uraninite, carnitite and pitchblende, etc. that come into contact with flowing water during its long mountainous course and seepage inside the earth.

The knowledge of the uranium level is important to the whole biotic community of our biosphere. The determination of U-content is of considerable interest to geologists, oceanographers, nuclear scientists and health physicists for various reasons, viz. developing new techniques for uranium prospecting in the case of river water, searching for new fuel in sea water and collecting information for public health services in the case of mineral and tap water. The knowledge of uranium levels in water samples is also important for environmental studies, viz. ecological changes brought about by uranium due to its absorption in plants and also for the assessment of its oral toxicity and effects on human kidney (Drury et al., 1981; Logett, 1989; Ortega et al., 1989). From the health hazard point of view, one is concerned due to the radioactive nuclides entering the human body mainly

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through food and water, which contain trace quantities of uranium. According to an estimate (Cothern and Lappenbusch, 1983) food contributes about 15% of the ingested uranium, while drinking water contributes about 85% to the human population in the U.S.A.

Uranium exists in the form of +2, +3, +4, +5 and +6 valance states, the most common being the hexavalent state. The hexavalent state is the most important in the case of water because almost all the tetravalent compounds are practically insoluble. After knowing the natural uranium contents one can also find the expected uranium alpha activity of the samples because from the known relative isotopic abundance of $^{235}$U, $^{238}$U and $^{234}$U in natural uranium as 99.27, 0.728 and 0.002%, respectively, the uranium alpha activity due to 1 µg of natural uranium will be 0.67 pCi.

2. EXPERIMENTAL DETAILS

Water samples were collected in small plastic bottles which were already cleaned with 3M HNO$_3$ solution and with double distilled water, and were also rinsed with the collected water. Melinex-O plastic sheets (thickness ≈ 100 µm) were cut into circular pieces of diameter 1.5 cm. These circular pieces coded with certain numbers were used as track detectors for the fission track registration. These detectors were washed thoroughly with 3M HNO$_3$ solution and dried in a clean oven. Then a small drop of water having known volume ($V = 0.0067 ± 0.00025$ ml) was dropped on the plastic detector surface with the help of a calibrated syringe filled with the desired water sample. The drop was dried inside an oven maintained at 80°C. The water evaporating leaving the non-volatile residue on the plastic detector surface. Another similar plastic detector sheet was placed in perfect contact with the above plastic containing the residue of the water drop, thus making a "sandwich" of the dried drop. Three "sandwiches" of dried drop were prepared for each water sample. All the sandwiched samples were then packed tightly by keeping them one on top of the other so as to fit in an aluminium cylinder of diameter 2.0 cm and height 5.3 cm. A standard glass dosimeter containing 0.77 ppm uranium by weight already determined in our laboratory (Kumar and Srivastava, 1984) was also sealed in a PVC plastic bag and kept in the aluminium cylinder for evaluating the total number of induced fission tracks. The standard glass dosimeter was broken to open a fresh surface and then etched in 48% HF at 23°C for 5 s. The track density in the thickness of the standard glass detector was determined by using the same magnification of 250×. The time integrated neutron flux or fluence (in neutron/cm$^2$) was determined by using the relation:

$$\phi = K \rho$$

where $K = (1.028 ± 0.008) \times 10^{10}$ neutrons/track for our glass (Kumar and Srivastava, 1984) and $\rho$ the observed track density (tracks/cm$^2$). The in situ neutron fluence in our case was found to be $4.69 \times 10^{8}$ neutrons/cm$^2$ (Singh, 1993).

The level of U-content in water (in wt/vol units) is calculated by the following relation given first by Fleischer and Lovett (1968).

$$C_u = \frac{TM}{VGNa_{\phi}E\phi} \text{ (g of U/l)}$$

where

- $T = \text{total number of fission tracks within the droplet area}$
- $M = \text{gram atomic mass of natural uranium}$ (238.03 mg/mole)
- $V = \text{volume of water drop (0.0067 ml, in our case)}$
- $G = \text{geometry factor for the registration of fission tracks (G = 1)}$
- $N_a = \text{Avogadro's number (6.02 \times 10^{23} \text{ molecules/g mole})}$
- $\sigma = \text{thermal fission cross-section for natural uranium (4.2 b)}$
- $E = 1 - (V_G/V_F)^2$, the etching efficiency factor (0.9902 for Melinex-O in our case; Singh, 1993).

Using the values of the constants in our case the above formula reduces to:

$$C_u = 3.025 \times 10^{-5}T \text{ (µg/l)}$$

3. RESULTS AND DISCUSSION

Table 1 shows the values of uranium concentrations in the individual water samples which were collected from different sources and locations in various cities of Uttar Pradesh (India). It is found that U-content in the drinking water samples (from taps, hand pumps and jet pumps) varies from reservoir to reservoir, tap to tap, hand pump to hand
Since the overall average intake of uranium into the pumps, rivers, etc.) and place to place. The tap water human body through tap and jet pump plus hand those from Kanpur, Allahabad and Jhansi (Table 1). samples from Ghaziabad contain more uranium than well within the range of reported results for other places. The tap water samples contain 0.6-19.2 µg l⁻¹ (Bansal et al., 1981) and U.S. drinking water samples contain 0.029-1948.9 µg l⁻¹ (Drury et al., 1983) and domestic Indian water samples contain 0.025 and 0.026 mg day, respectively, it is concluded that the uranium intake through drinking water samples from all these sources is much lower than the maximum permissible intake of 40 mg day (Morgan, 1973). From Table 2, it is also concluded that the untreated water samples from river streams have a lower average value of U-content than those from other sources. The average value of U-content for the case of tap water samples, is also found to be smaller than those either from hand pumps or jet pumps.

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REFERENCES
Table 1. Uranium content in some water samples from various sources and cities as determined by fission track analysis

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Sample code No.</th>
<th>Place and source of collection</th>
<th>Basic source</th>
<th>Total No. of tracks</th>
<th>U-concentration (in μg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>J1</td>
<td>Jal Kal Vibhag, Jhansi</td>
<td>dam</td>
<td>2883</td>
<td>0.87 ± 0.01</td>
</tr>
<tr>
<td>2</td>
<td>J1</td>
<td>Pasarat, Jhansi</td>
<td>dam</td>
<td>3633</td>
<td>1.10 ± 0.02</td>
</tr>
<tr>
<td>3</td>
<td>K1</td>
<td>Benajhabar Jal Nigam, Kanpur</td>
<td>river</td>
<td>8446</td>
<td>2.56 ± 0.03</td>
</tr>
<tr>
<td>4</td>
<td>Ad1</td>
<td>Allahabad Univ. campus Allahabad</td>
<td>tube-well</td>
<td>9311</td>
<td>2.82 ± 0.10</td>
</tr>
<tr>
<td>5</td>
<td>K1</td>
<td>Panki Thermal Power Station, Kanpur</td>
<td>tube-well</td>
<td>12,121</td>
<td>3.67 ± 0.11</td>
</tr>
<tr>
<td>6</td>
<td>Ad1</td>
<td>Railway Station, Allahabad</td>
<td>tube-well</td>
<td>12,530</td>
<td>3.79 ± 0.18</td>
</tr>
<tr>
<td>7</td>
<td>K1</td>
<td>Indian Institute of Technology, Kanpur</td>
<td>tube-well</td>
<td>13,230</td>
<td>4.00 ± 0.15</td>
</tr>
<tr>
<td>8</td>
<td>G1</td>
<td>Railway Station, Ghaziabad</td>
<td>tube-well</td>
<td>13,992</td>
<td>4.23 ± 0.27</td>
</tr>
<tr>
<td>9</td>
<td>G1</td>
<td>Ram Nagar, Ghaziabad</td>
<td>tube-well</td>
<td>19,354</td>
<td>5.86 ± 0.12</td>
</tr>
<tr>
<td>10</td>
<td>G1</td>
<td>Ramte Ram Road, Ghaziabad</td>
<td>tube-well</td>
<td>26,909</td>
<td>8.14 ± 0.14</td>
</tr>
<tr>
<td>11</td>
<td>G1</td>
<td>M.L. Govt. Hospital, Ghaziabad</td>
<td>tube-well</td>
<td>37,070</td>
<td>11.22 ± 0.23</td>
</tr>
<tr>
<td>12</td>
<td>G1</td>
<td>Raj Nagar Sector-I, Ghaziabad</td>
<td>tube-well</td>
<td>37,544</td>
<td>11.36 ± 0.34</td>
</tr>
</tbody>
</table>

B: hand pumps + C: jet pumps

13 | Ad1 | Clock Tower, Allahabad | hand pumps | 6679 | 2.02 ± 0.03 |
14 | K1  | Railway Station, Kanpur | jet pumps  | 10,941 | 3.31 ± 0.08 |
15 | J1  | Pasarat, Jhansi        | jet pumps  | 15,150 | 4.58 ± 0.06 |
16 | J1  | Jawahar Chowk, Jhansi  | hand pumps | 21,329 | 6.45 ± 0.19 |
17 | K4  | Panki Temple, Kanpur   | hand pumps | 29,976 | 9.07 ± 0.10 |
18 | Ad1 | Baluaghat, Allahabad Yamuna | river stream | 3053 | 0.92 ± 0.01 |
19 | Ad1 | Sangam, Allahabad Ganga | river stream | 4908 | 1.48 ± 0.06 |
20 | Ad1 | Gaughat, Allahabad Yamuna | river stream | 5274 | 1.60 ± 0.05 |
21 | Ad1 | Triveni (Sangam), Allahabad | river stream | 7693 | 2.33 ± 0.12 |
22 | G1  | G.T. Road Bridge, Ghaziabad, Hinden | river stream | 10,039 | 3.04 ± 0.05 |
23 | K4  | Puramarghat, Ganga Kanpur | river stream | 15,111 | 4.57 ± 0.06 |
24 | K4  | Bhainroghat, Kanpur Ganga | river stream | 17,737 | 5.37 ± 0.04 |

D: rivers

25 | K4  | Baluaghat, Allahabad Yamuna | river stream | 3053 | 0.92 ± 0.01 |
26 | Ad1 | Sangam, Allahabad Ganga | river stream | 4908 | 1.48 ± 0.06 |
27 | Ad1 | Gaughat, Allahabad Yamuna | river stream | 5274 | 1.60 ± 0.05 |
28 | Ad1 | Triveni (Sangam), Allahabad | river stream | 7693 | 2.33 ± 0.12 |
29 | G1  | G.T. Road Bridge, Ghaziabad, Hinden | river stream | 10,039 | 3.04 ± 0.05 |
30 | K4  | Puramarghat, Ganga Kanpur | river stream | 15,111 | 4.57 ± 0.06 |
31 | K4  | Bhainroghat, Kanpur Ganga | river stream | 17,737 | 5.37 ± 0.04 |

The errors shown are the counting errors evaluated from standard deviation values (σ) of three sandwiches (six surfaces) for each sample.

From Tables 1 and 2, it is seen that in the case of tap water supplied by the water works departments of the various cities, the value of uranium concentration varies from 0.87 to 11.36 μg/l with a mean value of 4.97 μg/l. Considering the basic source of jet pumps and hand pumps are the same (because the depths of their boreholes are not too different from each other), the values of U-content for this category of untreated water samples vary from 2.02 to 9.07 μg/l with a mean value of 5.09 μg/l. In the case of river water samples of the various cities collected directly from the river streams, the levels of uranium concentration are found to vary from 0.92 to 4.57 μg/l with a mean value of 2.76 μg/l.


RADON PROGENY (WL) CONCENTRATION STUDIES IN DIFFERENT KIND OF ROOMS USING LR-115 TYPE II LASTIC TRACK DETECTORS

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ABSTRACT
Monitoring of indoor radon has acquired an international importance after the realization of the fact that inhalation of high concentration of it may cause lung cancer. Measurement of radon progeny concentration in terms of working level (WL) is essential for calculating the effective dose-equivalent received by the population. Since the radon concentration has been observed to vary with different parameters such as ventilation rate, type of building material used in the construction, the soil underlying the house and even the life style of the occupants, hence a time integrated measurement using passive detectors is necessary in order to get a reliable average value of dose-equivalent calculation. In the present study we have measured radon WL concentration in different kind of ground floor rooms in Aligarh (India) using the passive detector LR-115 type II. The details of measurement and results are presented and discussed.

1. INTRODUCTION
Various air pollutants are present in our ambient environment. Commonly reported pollutants are carbon mono-oxide, nitrogen oxide, volatile organic compounds, radon and its progeny and air borne particles. Among these pollutants inhalation of radon and its progeny (216 Po and 214 Po) increase the risk of lung cancer. About 52% of the total radiation dose received by the Indian population is due to inhalation of indoor radon progeny (Narayanan, et. al., 1991)

The main sources of radon inside a house are the emanation from the soil underneath and from the building materials used in the construction of the house. Other sources like water and natural gas contribute minutely, de facto their contribution depends on the origin of water and gas and even on the rate of their consumption. Several factors determine the concentration of radon and its progeny in a dwelling. Parameters such as ventilation rate (Abu-Jarad and Fremlin, 1983), moisture and temperature (Straden and Kolstad, 1984) and type of rock underlying the dwelling (Gunby et al., 1993) influence the indoor radon concentration. Diurnal and seasonal variations (Abu-Jarad and Fremlin, 1983) contribute significantly to the overall average radon concentration in the air inside the house.
1984, Lloyd, 1983) have also been observed. The construction and integrity of floor and habits and preferences regarding coating material on the walls also modify the concentration of radon and its progeny inside the house. In the present study we have studied the effects of ventilation, type of floor and whitewash etc. on the concentration of radon progeny inside dwellings.

2. EXPERIMENTAL DETAILS

LR-115 type-II track detectors of size 2.0 cm x 1.5 cm were used as passive detectors in "BARE" mode (After and Fleischer, 1981) for recording the tracks of alpha particles emitted by $^{222}$Rn gas present in the ambient air and also its short lived daughters, typically 218 Po and 214 which generally attach themselves to the aerosols. Detector pieces were fixed on thick cards and mounted on the wall with their sensitive surfaces facing the air, taking due care that there was nothing to obstruct the detectors within a hemispherical volume of radius 9.1 cm in front of them. It was necessitated to avoid the 'plate-out' effect. Such cards were mounted in different rooms having the following characteristics:

(i) Rooms of same type constructed at one time with almost same building materials but having different ventilation conditions by their occupants.

(ii) Rooms in a locality having the same volume and same doors but different type of floor.

(iii) Rooms in a locality having different type of coating material on the walls.

(iv) Different positions in a single room.

(v) Different rooms of a single house.

The detectors were left to record the alpha tracks arising out of the decay of radon and its progeny for a period of about 3 months. After the exposure the submicroscopic track were revealed by etching the detectors in 2.5 N, NaOH solution maintained at 60°C for 2 hours. Thereafter, the detector were washed in running water and dried. The track density of 'through-etched-holes' was calculated by scanning under an optical microscope at a magnification of 100X. The background track density was separately evaluated for each detector sheet before mounting.

The potential alpha energy concentration (PAEC), $C_p$ in WL was calculated using the relation.

$$C_p = \rho / K \times t$$

where $\rho$ is the track density obtained after subtracting the background, $K$ is the sensitivity factor and $t$ is the total time of exposure. Sensitivity factor of 625 tracks cm$^{-2}$ d$^{-1}$ per WL as determined by us (Srivastav et. al., 1995) was used.

The effective dose-equivalent was calculated using a conversion factor of 3.88 mSv/WLM and occupancy factor of 0.80 (ICRP-65, 1993)
3. RESULTS AND DISCUSSION

Table 1 shows the variation of concentration of radon progeny in same type of house having different ventilation conditions by the occupants. The PAEC varies from 6.22 mWL to 14.45 mWL and the effective dose-equivalent varies from 1.0 mSv/y to 2.3 mSv/y. Although the houses were built at the same time and using almost the same building materials but there is a prominent difference in the PAEC.

Table 1

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Category &amp; House No.</th>
<th>Detector Code</th>
<th>PAEC (mWL)</th>
<th>Eff. Dose-Equi. (mSv/y⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>B-06</td>
<td>B1</td>
<td>14.12</td>
<td>2.3</td>
</tr>
<tr>
<td>2.</td>
<td>B-13</td>
<td>B2</td>
<td>7.79</td>
<td>1.3</td>
</tr>
<tr>
<td>4.</td>
<td>B-23</td>
<td>B4</td>
<td>8.71</td>
<td>1.4</td>
</tr>
<tr>
<td>5.</td>
<td>B-26</td>
<td>B5</td>
<td>6.22</td>
<td>1.0</td>
</tr>
</tbody>
</table>

This clearly shows the effect of ventilation. The higher value of PAEC were found in houses of those couple who were both employed and so the rooms remained closed most of the time.

Table 2 presents the variation of PAEC in rooms located in the same colony but having different white washing material. The PAEC varies from 2.84 mWL to 16.05 mWL and the effective dose-equivalent varies from 0.5 mSv/y to 2.6 mSv/y. Unplastered and without whitewash room has the maximum value of PAEC while plastered and painted with oil paints has the minimum value of PAEC. This is due to the fact that unplastered room is more porous than plastered and oil paint fills the pores thereby decreasing the exhalation from the building material.

Table 2

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Description</th>
<th>Detector Code</th>
<th>PAEC (mWL)</th>
<th>Eff. Dose-Equi. (mSv/y⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Unplastered</td>
<td>H05</td>
<td>16.05</td>
<td>2.6</td>
</tr>
<tr>
<td>2.</td>
<td>Plastered</td>
<td>H02</td>
<td>13.69</td>
<td>2.2</td>
</tr>
<tr>
<td>3.</td>
<td>White wash</td>
<td>H10</td>
<td>7.24</td>
<td>1.2</td>
</tr>
<tr>
<td>4.</td>
<td>Colour wash</td>
<td>H19</td>
<td>6.41</td>
<td>1.0</td>
</tr>
<tr>
<td>5.</td>
<td>Distemper</td>
<td>H06</td>
<td>3.99</td>
<td>0.6</td>
</tr>
<tr>
<td>6.</td>
<td>Oil paint</td>
<td>H07</td>
<td>2.84</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Table 3 depicts the variation of radon progeny level in rooms in the same locality but having different type of floors. The PAEC varies from 3.92 mWL to 16.26 mWL and the effective dose-equivalent varies from 0.6 mSv/y to 2.6 mSv/y. The bare earthen floor has the maximum value of PAEC. It is due to uninterrupted exhalation of radon from the soil. The flooring material reduces the exhalation from the soil. It is seen that mosaic floor can reduce the value PAEC about 4 times.

Table 3  
Variation of PAEC and Eff. Dose-Equi. in rooms having different type of floors

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Description of floor</th>
<th>Detector Code</th>
<th>PAEC (mWL)</th>
<th>Eff. Dose-Equi. (mSv y⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Earthen (Kachcha)</td>
<td>H 20</td>
<td>16.26</td>
<td>2.6</td>
</tr>
<tr>
<td>2.</td>
<td>Brick</td>
<td>H 13</td>
<td>8.67</td>
<td>1.4</td>
</tr>
<tr>
<td>3.</td>
<td>Cemented</td>
<td>H 14</td>
<td>6.31</td>
<td>1.0</td>
</tr>
<tr>
<td>4.</td>
<td>Cemented covered with carpet</td>
<td>H 29</td>
<td>5.82</td>
<td>0.9</td>
</tr>
<tr>
<td>5.</td>
<td>Mosaic</td>
<td>H 33</td>
<td>3.92</td>
<td>0.62</td>
</tr>
</tbody>
</table>

Table 4 shows the variation of PAEC in a room at different positions. Results of detectors mounted at four walls of a room at the same height shows that the value of PAEC varies from 7.22 mWL to 9.35 mWL and the effective dose-equivalent varies from 1.2 mSv/y to 1.5 mSv/y. The detectors were also mounted near the two ventilators. It was observed that the value of PAEC was higher near the open ventilator (8.43 mWL) than the value of PAEC near the closed ventilator (6.67 mWL). This clearly indicates the effects of air draughts near the ventilators. When the ventilator is open, the indoor air escape swiftly from the ventilaor. It has been observed by Kwapullinski and Nowak (1984) that a directly proportional relationship exit between increased content of radon decay products and faster wind velocity in the range of 0.5-4.5 m/s.

Table 4  
Variation of PAEC and Eff. Dose-Equi. at different positions in a room

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Description</th>
<th>Detector Code</th>
<th>PAEC (mWL)</th>
<th>Eff. Dose-Equi. (mSv y⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>North wall</td>
<td>C 37</td>
<td>7.22</td>
<td>1.2</td>
</tr>
<tr>
<td>2.</td>
<td>South wall</td>
<td>C 36</td>
<td>9.35</td>
<td>1.5</td>
</tr>
<tr>
<td>3.</td>
<td>East wall</td>
<td>C 35</td>
<td>8.40</td>
<td>1.3</td>
</tr>
<tr>
<td>4.</td>
<td>West wall</td>
<td>C 38</td>
<td>9.06</td>
<td>1.4</td>
</tr>
<tr>
<td>5.</td>
<td>Ventilator open</td>
<td>C 44</td>
<td>8.43</td>
<td>1.3</td>
</tr>
<tr>
<td>6.</td>
<td>Ventilator Closed</td>
<td>C 43</td>
<td>6.67</td>
<td>1.1</td>
</tr>
</tbody>
</table>
Table 5 presents the variation of PAEC in different rooms of a house. It is evident from the table that PAEC varies from 6.54 mWL to 12.24 mWL. The minimum value of 6.54 mWL was found in the outer room having two big windows facing each other and making a cross ventilation. The highest value of PAEC was found in the kitchen. It may be attributed to the small ventilation in the kitchen. Further, the burning of natural gas (LPG) in the kitchen may also contribute in increasing the amount of PAEC.

Table 5

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Description</th>
<th>Detector Code</th>
<th>PAEC (mWL)</th>
<th>Eff. Dose-Equi. (mSv y⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Outer Room</td>
<td>C 50</td>
<td>6.54</td>
<td>1.0</td>
</tr>
<tr>
<td>2.</td>
<td>Drawing Room</td>
<td>C 54</td>
<td>9.06</td>
<td>1.4</td>
</tr>
<tr>
<td>3.</td>
<td>Bed Room</td>
<td>C 36</td>
<td>9.35</td>
<td>1.5</td>
</tr>
<tr>
<td>4.</td>
<td>Study Room</td>
<td>C 32</td>
<td>8.49</td>
<td>1.3</td>
</tr>
<tr>
<td>5.</td>
<td>Kitchen</td>
<td>C 52</td>
<td>12.24</td>
<td>2.0</td>
</tr>
<tr>
<td>6.</td>
<td>Toilet</td>
<td>C 34</td>
<td>8.67</td>
<td>1.4</td>
</tr>
</tbody>
</table>

REFERENCES


Kwapulinski E. and Nowak B. (1984) 'Effect of some meteorological factors on content change of radon decay products' GIG. SANIT, 8, 75.


