CHAPTER I

GENERAL INTRODUCTION
(AN OVER VIEW OF RADON)
1.1 Introduction

The increasing awareness about the harmful effects of natural radiation demands that all sources of natural radiation must be monitored. Most of such radiations we receive in the normal course of events are composed of: (a) cosmic rays, (b) gamma- rays, and (c) radon gas. Cosmic rays originate from the sun and outer space. The gamma rays are emitted by naturally occurring radioactive elements in the earth’s crust. The main radioactive elements in the earth’s crust are $^{40}\text{K}$, $^{238}\text{U}$ and $^{232}\text{Th}$ series etc. Half- lives of above radioactive elements in the earth are very long. The magnitude of the dose received by an individual from these sources depends on the environments, types of rocks, surrounding soil etc. The estimated equivalent radiation dose from these sources (gamma-rays) is reported to be about 0.35 mSv per year$^1$. A schematic diagram of natural background radiation dose is shown in fig.1.
Over the past few decades, there has been a large scientific interest in the study of environmental radon. One of the main reasons is its associated health hazard, another is its wide spread use as an environmental tracer, \(^2\) earthquake prediction.

Amongst the natural decay series products, radon is an important source of natural radiation. It is estimated that 50-55% of the average annual dose from natural background radiation is contributed by \(^{222}\text{Rn}\) alone. \(^4\)

Radon is a naturally occurring radioactive gas found in soils, rock, building materials, natural gas and water. It has the symbol \(\text{Rn}\) having atomic number 86. Radon was discovered in 1900 by Friedrich Ernst Dorn (Germany), who called it radium emanation. In 1908 William Ramsay and Robert Whytlaw-Gray, named it niton (Latin nitens meaning "shining"; symbol \(\text{Nt}\)) and isolated it, determined its density, and determined that it was the heaviest known gas. It has been called "radon" since 1923. Its position in the periodic table is in \(\text{VIII}^{\text{th}}\) group of \(\text{VI}^{\text{th}}\) Period. Its specific gravity, boiling point and freezing point are 9.73, 211 K and 202 K respectively. \(^5\) It is one of the noble gases and so should have been inert. However, some investigators. \(^6\), \(^7\), \(^8\) have reported that, like xenon, radon (though a noble gas) too has been successfully reacted with liquid bromine trifluoride and some solid complexes of antimony halides. When it is cooled below the freezing point, radon exhibits a brilliant phosphorescence which becomes yellow as the temperature is lowered and orange-red at the temperature of liquid air. The volume corresponding to an activity of 1 picocurie (Pci) of radon is about \(6.7 \times 10^{-19} \text{ cm}^3\) and the corresponding partial pressure is less than \(10^{-18} \text{ atmospheres}\). \(^9\) The average atmospheric concentration of radon is of the order of \(6 \times 10^{-18} \%\) by volume. \(^10\) Radon has no immediate
health effects, but its short-lived (solid particulate) daughter products that are the main health risks\textsuperscript{11}. It is a colourless, odourless and tasteless and can only be studied using special equipment.

After emanation when radon enters an enclosed space, it can sometimes accumulate to unacceptably high concentrations. In open air it is quickly diluted to harmless concentrations.

Radon is also fairly soluble in water and organic solvents. Although reaction with other compounds is comparatively rare, it is not completely inert and forms stable molecules with high electronegative materials. This noble gas also occurs mostly in two isotopic forms viz.\textsuperscript{222}Rn and \textsuperscript{220}Rn.

The atomic radius of Rn is 1.34 Å and it is the heaviest known gas, almost nine times denser than air. It is a single atom gas and it easily penetrates many common materials like paper, leather, low density plastic (like plastic bags etc.), most paints and building materials like gypsum board (sheetrock), concrete block, mortar, sheathing paper (tarpaper), wood paneling and most thermal insulation.

There are thirty four known isotopes of radon (Rn). Out of these, the most stable isotope of radon is \textsuperscript{222}Rn, which is a decay product of \textsuperscript{226}Ra, in Uranium-238 and has a half-life of 3.825 days and emits alpha particles. \textsuperscript{220}Rn is also a natural decay product of \textsuperscript{224}Ra in Thorium-232 decay series and is called “thoron”. It has a half-life of 55.6 seconds and also emits alpha radiation. \textsuperscript{219}Rn is derived from actinium (Uranium-235) is called “actinon,” is an alpha emitter and has a half-life of 3.96 seconds. Because of its very
short half-life (3.96 seconds) and environmental concentrations of actinon is very low
(0.7%), so their contribution to human exposure is negligible.

The decay series of three primordial radionuclides U-238, Th-232, and U-235 are shown
in the radioactive decay series Fig.2, Fig.3, and Fig.4 and their half lives are shown in
Table 1.1, Table 1.2, and Table 1.3.¹²
Figure 2: Natural Decay Series: Uranium-238
Table 1.1: Radioactive series of $^{238}$U (Sharma B.K., 1996)

<table>
<thead>
<tr>
<th>NAME AND SYMBOL</th>
<th>MASS NUMBER</th>
<th>ATOMIC NUMBER</th>
<th>RADIATION</th>
<th>HALF LIFE PERIOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uranium (U)</td>
<td>238</td>
<td>92</td>
<td>$\alpha$</td>
<td>$4.5 \times 10^9$ years</td>
</tr>
<tr>
<td>Thorium (Th)</td>
<td>234</td>
<td>90</td>
<td>$\beta$</td>
<td>24.6 days</td>
</tr>
<tr>
<td>Protactinium (Pa)</td>
<td>234</td>
<td>91</td>
<td>$\beta$</td>
<td>1.14 min.</td>
</tr>
<tr>
<td>Uranium (U)</td>
<td>234</td>
<td>92</td>
<td>$\alpha$</td>
<td>$2.7 \times 10^2$ years</td>
</tr>
<tr>
<td>Thorium (Th)</td>
<td>230</td>
<td>90</td>
<td>$\alpha$</td>
<td>$8.3 \times 10^4$ years</td>
</tr>
<tr>
<td>Radium (Ra)</td>
<td>226</td>
<td>88</td>
<td>$\alpha$</td>
<td>1590 years</td>
</tr>
<tr>
<td>Radon (Rn)</td>
<td>222</td>
<td>86</td>
<td>$\alpha$</td>
<td>3.8 days</td>
</tr>
<tr>
<td>Polonium (Po)</td>
<td>218</td>
<td>84</td>
<td>$\alpha$</td>
<td>3.0 min.</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>214</td>
<td>82</td>
<td>$\beta$</td>
<td>26.7 min.</td>
</tr>
<tr>
<td>Bismuth (Bi)</td>
<td>214</td>
<td>83</td>
<td>$\beta$</td>
<td>19.7 min.</td>
</tr>
<tr>
<td>Polonium (Po)</td>
<td>214</td>
<td>84</td>
<td>$\alpha$</td>
<td>$1.5 \times 10^{-4}$ sec</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>210</td>
<td>82</td>
<td>$\beta$</td>
<td>22 years</td>
</tr>
<tr>
<td>Bismuth (Bi)</td>
<td>210</td>
<td>83</td>
<td>$\beta$</td>
<td>4 days</td>
</tr>
<tr>
<td>Polonium (Po)</td>
<td>210</td>
<td>84</td>
<td>$\alpha$</td>
<td>140 days</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>206</td>
<td>82</td>
<td>-</td>
<td>Stable</td>
</tr>
</tbody>
</table>
Figure 3: Natural Decay Series: Thorium - 232
Table 1.2: Radioactive series of $^{232}$Th (Sharma B.K., 1996)

<table>
<thead>
<tr>
<th>NAME AND SYMBOL</th>
<th>MASS NUMBER</th>
<th>ATOMIC NUMBER</th>
<th>RADIATION</th>
<th>HALF LIFE PERIOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thorium (Th)</td>
<td>232</td>
<td>90</td>
<td>$\alpha$</td>
<td>$1.4 \times 10^{10}$ years</td>
</tr>
<tr>
<td>Radium (Ra)</td>
<td>228</td>
<td>88</td>
<td>$\beta$</td>
<td>6.7 years</td>
</tr>
<tr>
<td>Actinium (Ac)</td>
<td>228</td>
<td>89</td>
<td>$\beta$</td>
<td>6.13 hours</td>
</tr>
<tr>
<td>Thorium (Th)</td>
<td>228</td>
<td>90</td>
<td>$\alpha$</td>
<td>1.9 years</td>
</tr>
<tr>
<td>Radium (Ra)</td>
<td>224</td>
<td>88</td>
<td>$\alpha$</td>
<td>3.65 days</td>
</tr>
<tr>
<td>Radon (Rn)</td>
<td>220</td>
<td>86</td>
<td>$\alpha$</td>
<td>55 sec</td>
</tr>
<tr>
<td>Polonium (Po)</td>
<td>216</td>
<td>84</td>
<td>$\alpha$</td>
<td>0.16 sec</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>212</td>
<td>82</td>
<td>$\beta$</td>
<td>10.6 hours</td>
</tr>
<tr>
<td>Bismuth (Bi)</td>
<td>212</td>
<td>83</td>
<td>$\alpha$</td>
<td>1 hour</td>
</tr>
<tr>
<td>Thallium (Tl)</td>
<td>208</td>
<td>81</td>
<td>$\beta$</td>
<td>3.1 min</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>208</td>
<td>82</td>
<td>-</td>
<td>Stable</td>
</tr>
</tbody>
</table>
Figure 4: Natural Decay Series: Uranium - 235
Table 1.3: Radioactive series of $^{238}\text{U}$ (Sharma B.K., 1996)

<table>
<thead>
<tr>
<th>NAME AND SYMBOL</th>
<th>MASS NUMBER</th>
<th>ATOMIC NUMBER</th>
<th>RADIATION</th>
<th>HALF LIFE PERIOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uranium (U)</td>
<td>235</td>
<td>92</td>
<td>$\alpha$</td>
<td>$7.3 \times 10^8$ years</td>
</tr>
<tr>
<td>Thorium (Th)</td>
<td>231</td>
<td>90</td>
<td>$\beta$</td>
<td>25.6 hours</td>
</tr>
<tr>
<td>Protoactinium(Pa)</td>
<td>231</td>
<td>91</td>
<td>$\alpha$</td>
<td>$3.28 \times 10^4$ years</td>
</tr>
<tr>
<td>Actinium (Ac)</td>
<td>227</td>
<td>89</td>
<td>$\beta$</td>
<td>21.6 years</td>
</tr>
<tr>
<td>Thorium (Th)</td>
<td>227</td>
<td>90</td>
<td>$\alpha$</td>
<td>18.17 days</td>
</tr>
<tr>
<td>Radium (Ra)</td>
<td>223</td>
<td>88</td>
<td>$\alpha$</td>
<td>11.68 days</td>
</tr>
<tr>
<td>Radon (Rn)</td>
<td>219</td>
<td>86</td>
<td>$\alpha$</td>
<td>3.92 sec</td>
</tr>
<tr>
<td>Polonium (Po)</td>
<td>215</td>
<td>84</td>
<td>$\alpha$</td>
<td>$1.83 \times 10^3$ sec</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>211</td>
<td>82</td>
<td>$\beta$</td>
<td>36.1 min</td>
</tr>
<tr>
<td>Bismuth (Bi)</td>
<td>211</td>
<td>83</td>
<td>$\beta$</td>
<td>2.16 min</td>
</tr>
<tr>
<td>Polonium (Po)</td>
<td>211</td>
<td>84</td>
<td>$\alpha$</td>
<td>0.52 sec</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>207</td>
<td>82</td>
<td>-</td>
<td>Stable</td>
</tr>
</tbody>
</table>

The activity (rate of decay) of $^{222}\text{Rn}$ is expressed in units called curies. The curie is based on the rate of decay of one gram of $^{226}\text{Ra}$ or $3.7 \times 10^7$ disintegrations per second. The International System of Units (SI) measure of activity is Becquerels per cubic meter (Bq/m$^3$).

One Bq. equals 1 disintegration per second.

### 1.2 Mechanisms of Radon Migration (In Brief)

Radon is a noble gas and thus does not undergo chemical reactions which could preclude its free movement within soil. When radon is free to move, after it left its original matrix, it arrives at the soil surface following different mechanisms of migration and then exhales to the atmosphere. The first mechanism of migration is diffusion. The second one is convection, which can occur when a sufficient thermal gradient is available within the
soil, depending on many local parameters, such as viscosity, porosity, permeability through pore spaces in the soil, fractures in the rocks and along with weak zones such as shear, faults, thrust, etc. The third one is transport by means of gas carrier.\textsuperscript{13-15} Moisture content in the soil can increase radon emanation to some extent, but if the soil pores become saturated emission is inhibited.\textsuperscript{16} For some geological situations, radon migrates long distances from its place of origin and can be detected by alpha-particle recorders at the earth’s surface.\textsuperscript{17,18}

1.3 Radon Progenies

The first four short-lived decay products of radon are, \textsuperscript{218}Polonium, \textsuperscript{214}Lead, \textsuperscript{214}Bismuth and \textsuperscript{214}Polonium, with half-lifes of 3.10 minutes, 26.8 minutes, 19.9 minutes and 0.1643 ms, which decay alpha, beta, beta and alpha respectively.

At the next step, \textsuperscript{214}Po decays to \textsuperscript{210}Pb, which has a much longer half-life of 22 years. Its progenies are:

\textsuperscript{210}Bismuth, a beta emitter having half-life 4 days,

\textsuperscript{210}Polonium, an alpha emitter having half-life 140 days,

\textsuperscript{206}Lead, stable.

\textsuperscript{222}Rn progeny exposure rates have been expressed as working levels (WLs). 1 WL is defined as any combination of short-lived \textsuperscript{222}Rn progeny (\textsuperscript{218}Po, \textsuperscript{214}Pb, \textsuperscript{214}Bi and \textsuperscript{214}Po) in
1 liter of air that releases $1.3 \times 10^5$ Mev of potential alpha energy. The value of $1.3 \times 10^5$ Mev derives from the energy produced by complete decay of the short-lived $^{222}\text{Rn}$ progeny in radioactive equilibrium with 100 pCi/ L of $^{222}\text{Rn}$. It is expressed in table 1.4.19

### Table 1.4: Required data for calculation of Working Level

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>$\alpha$ Energy(MeV)</th>
<th>Half-life</th>
<th>Number of Atoms</th>
<th>Ultimate $\alpha$ Energy(MeV)</th>
<th>Total $\alpha$ Energy(MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{218}\text{Po}$</td>
<td>6.00</td>
<td>3.10 min</td>
<td>977</td>
<td>6.00+7.69</td>
<td>0.134 x 10$^5$</td>
</tr>
<tr>
<td>$^{214}\text{Pb}$</td>
<td>0</td>
<td>26.8 min</td>
<td>8580</td>
<td>0+7.69</td>
<td>0.659 x 10$^5$</td>
</tr>
<tr>
<td>$^{214}\text{Bi}$</td>
<td>0</td>
<td>19.9 min</td>
<td>6310</td>
<td>0+7.69</td>
<td>0.485 x 10$^5$</td>
</tr>
<tr>
<td>$^{214}\text{Po}$</td>
<td>7.69</td>
<td>0.1643 ms</td>
<td>0.0008</td>
<td>7.69</td>
<td>0.006125 x 10$^5$</td>
</tr>
</tbody>
</table>

Total = 1.3 x 10$^5$

One WL is equivalent to $2.08 \times 10^5$ joules per cubic meter of air (J/m$^3$). A unit that incorporates both dose and time is the working level month (WLM). Exposure of 1 WL for 1 working month (170 hours) equals 1 WLM cumulative exposure. The SI unit of cumulative exposure is expressed in joule-hours per cubic meter (jh/m$^3$). One WLM is equivalent to $3.5 \times 10^{-3}$ jh/m$^3$.

The radon equilibrium factor is the ratio between the activity of all short-period radon progenies (which are responsible for most of radon's biological effects), and the activity that would be at equilibrium with the radon parent.
1.4. Why the interest in Radon

Radon emanation and migration in the earth and in the atmosphere have been the interest of various studies in different countries including U.S.A., Russia, China, and India.

Radon’s unique properties as a naturally occurring radioactive gas have led to its use as a geophysical tracer for locating buried faults and geological structures, in exploring for uranium.\(^{20,21}\) Some researchers are studying possibility of using elevated soil-gas radon concentrations, or rapid changes in soil or groundwater radon concentrations, for predicting earthquakes.\(^{22-27}\) Anomalous radon changes in ground water and soil gas have been reported for a number of earthquakes at stations located several hundred kilometres from their epicentre.\(^{28,29}\) Although results of these studies are not yet found to be convincing, several groups are working on this aspect of radon emission.

Radon soil-concentration has been used in an experimental way to map buried close-subsurface geological faults, because concentrations are generally higher over the faults. Similarly it has found some limited use in geothermal prospecting.

Radon emanation from the soil varies with soil type and with surface uranium content, so outdoor radon concentrations can be used to track air masses to a limited degree. This fact has been put to use by some atmospheric scientists.

Radon has also been used as a tracer in the study of atmospheric transport process.\(^{30,31}\)

There have been several applications of radon in meteorology, water research and medicine.\(^{32}\) The correlation between radon and seismic activity was made by Shiratoi in 1927, based on some studies carried out in hot springs.\(^{33}\)

Extensive use of noble gas isotopes as tracers for studies connected with oceanography, limnology (study of lakes, streams and other bodies of fresh water) and hydrogeology are
reported in the literature. Some examples of these applications are: 1] studies of deep water formation and circulation, 2] ocean atmospheric exchange, 3] use of radon and helium rich springs issuing in rivers to trace flow patterns, 4] ground water discharge and 5] dating of ground waters. Although the short half-life of 3.825 days of radon limits its application to hydrological processes, its widespread occurrence and relative high specific activity coupled with simple instrumentation makes it useful for such applications.

Much attention, however, has been given to radon as a radiological health hazard, which is briefly discussed below.

1.5. Health Effects and Epidemiology

Radon levels in the outdoor air are relatively low, however, when Radon enters a house it can build up to levels which pose a significant health risk to the occupants. Radon is one of the earliest known occupational carcinogens among the radioactive elements.

Radon is not chemically active. It does not react with body tissues. While some inhaled radon does dissolve in the body fluids, the resulting concentration is so low that the radiation dose from the radon gas itself is negligible. It is the radon decay products that cause the damaging health effects when breathed in. The greater the amount of radon in the air, the greater is the potential of developing lung cancer.

When Radon undergoes the process of radioactive decay, new particles like $^{218}$Polonium, $^{214}$Lead, $^{214}$Bismuth and $^{214}$Polonium are created. These Radon decay products are also called "Radon daughters" and unlike to the Radon gas they are solid
particles. The problem is that the Radon daughters are radioactive substances. Most of the Radon daughters become attached to tiny dust particles (aerosols) in the indoor air. When these particles are inhaled, a fraction of them is deposited in the lungs. Inside the lung, radon daughters emit alpha particles that are absorbed in the nearby lung tissues. The resulting radiation dose increases the risk of lung cancer.

The build up of this radon daughter in the lung and their subsequent movement through the body of the lymphatic system and blood vessels may result not only in lung cancer but other forms of cancers also throughout the body. Henshaw et al,\(^{37}\) claimed that indoor radon exposure is associated with the risk of leukemia and certain other cancers such as melanoma and cancers of kidney and prostrate. The tissues at risk from exposure to Rn and its progeny include the epithelium of bronchi, Segmental bronchioles and alveolar membranes. The most important tissue is the bronchiode epithelium, which is the site of most lung cancers thought to be induced by radiation.\(^{38,39}\)

Over the last two decades a quite few studies on association between indoor radon level and lung cancer incidence have been made. Although some studies are inconclusive, some others indicate a positive correlation between radon levels and lung cancer.\(^{40-48}\) Some other studies, on the other hand have shown an absence of any such correlation.\(^{49-51}\)

Evidence derived from ecologic studies has been critically reviewed recently with special relevance to radon.\(^{52}\) The authors conclude that the 15 largest ecologic studies they
reviewed did not contribute to better understanding of the quantitative risks of indoor radon.

International Commission for Radiological Protection (ICRP) is of the opinion that some remedial measures against radon in dwellings are always necessary. The commission also recommends that action levels should be within a range of about 3-10 mSv. The radon concentration corresponding to the above range is about 200-600 Bq.m\(^{-3}\) with an annual occupancy of 7000 hours.

1.6. Sources of Radon

1.6.1 Soils and Rocks as the source of Radon

Certain soils and rocks that contain high levels of uranium also contain natural deposits of radon. These are,

a) Granite
b) Phosphate
c) Shale
d) Pitchblende

Radon is continually being formed in soil and released to air as a result of the extended half-life decay of uranium and radium and their abundance in the earth's surface. Atmospheric radon is not an issue of health concern because the radon is rapidly diluted to low levels by circulation throughout outdoor air.

There are no sinks for radon, and it is estimated that only negligible quantities escape to the stratosphere. As a result, the ultimate and sole fate of radon-222 is transformation or degradation through radioactive decay. Radon decays only through normal radioactive processes, meaning, an atom of radon emits an alpha particle resulting...
in an atom of Po-218, which in turn, also undergoes alpha particle emission to produce other radon progeny.

The radon concentration in the soil is a function of

a) The radium concentration
b) The soil moisture content
c) The soil particle size.
d) The rate of exchange of soil-entrapped air pockets with the atmosphere.

After radon is produced at the soil particulate level from the radioactive decay of radium, it is released into small air or water containing pores between soil and rock particles.

This transportation of radon throughout soil is primarily accomplished through alpha recoil and the mechanical flow of air and water throughout the soil.

Transportations throughout soil and within these pores are also somewhat facilitated by diffusion and convection. The diffusion constants for radon in air and water, $10^{-2}\text{cm}^2/\text{sec}$ and $10^{-5}\text{cm}^2/\text{sec}$, respectively, indicate that diffusion of radon is a relatively slow process and the movement of radon is therefore not significantly effected by this mechanism.

After radon is released into the pore spaces, the efficiency of its eventual release into ambient air, termed exhalation, is a function of

a) The soil porosity
b) The concentration of radon in the soil/gas pore.
c) Meteorological factors, including precipitation and atmospheric pressure.
Following the release into ambient air, the dispersion of radon is primarily determined by atmospheric, including vertical temperature gradients and direction of wind's force, and turbulence.

1.6.2. Water as the source of radon

Ground water that is in contact with radium containing rock and soil will be a receptor of radon emanating from the surroundings.

In ground water, radon transportation is determined primarily by:

a) Diffusion patterns

b) The direction of the water's mechanical flow.

The solubility of radon in water is relatively low, and with its short radioactive half life, much of it will decay before it has the opportunity of release from the groundwater.

When radon containing ground water reaches the surface by natural or man-made forces, the radon will inevitably be outgassed into the atmosphere.

Although the majority of radon present in groundwater will decay prior to its arrival at the surface, groundwater is nevertheless considered the second most prominent source of environmental radon and has been estimated to contribute approximately $5 \times 10^8$ Ci radon –222 per year to the atmosphere. Radon is also minimally released from water located at or slightly beneath the ocean's surface.

Radon concentrations in surface water supplies are usually relatively low. Municipal water supplies are typically aerated resulting in diminished radon levels.

Rural household wells may have potentially high levels of radon contamination. Deep aquifers have highly variable radon levels. Levels depend on:-
a) Uranium content of the rock
b) Distribution of the aquifer relative to the rock.
c) Groundwater flow patterns.

1.6.3. Natural gas as the source of radon

Natural gas may also be a source of radon. Like ground water, natural gas can accumulate Rn gas from Radium content in the rock structures, surrounding the gas formation. It is estimated that at a typical residential gas use and air exchange rates, even for unventilated gas appliances, the contribution to indoor Rn from natural gas is less than 4 Bq.m$^{-3}$.$^{54}$

In some regions, natural gas used for cooking and heating contains elevated concentrations of radon, which is released on combustion. Normally this source is not significant, and it can be monitored at transmission and distribution points. Typically the radon levels in natural gas is about 1000 Bq.m$^{-3}$. Natural gas as supplied usually contains gas from a number of wells and fields and thus can vary over time, depending on the proportions supplied by different sources.$^{55}$

1.6.4. Building materials as the source of radon

Building materials are more easily characterized as indoor radon source than the soil or rock. Table 1.5 gives the radioactivity content in building materials used for building construction in India.$^{56}$ Ingersoll in 1983 has measured the Rn emanation rates for a number of building materials. In concrete, the estimated emanation rate (average) is $7.7 \times 10^{-6}$ Bq.Kg$^{-1}$.Sec$^{-1}$. For gypsum, it was found to be about $6.3 \times 10^{-6}$ Bq.Kg$^{-1}$.Sec$^{-1}$. $^{57}$ In table 1.5 radioactivity content in few building materials used in India are shown.
Table 1.5: Radioactivity content in building materials used for building construction in India (Ramachandran, 1998)

<table>
<thead>
<tr>
<th>Material</th>
<th>K⁴⁰ Activity in Bq.Kg⁻¹</th>
<th>Ra²⁶ Activity in Bq.Kg⁻¹</th>
<th>Th²³² Activity in Bq.Kg⁻¹</th>
<th>Radium Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>5 - 385</td>
<td>16 - 377</td>
<td>8 - 78</td>
<td>40 - 440</td>
</tr>
<tr>
<td>Brick</td>
<td>130 - 1390</td>
<td>21 - 48</td>
<td>26 - 126</td>
<td>88 - 311</td>
</tr>
<tr>
<td>Stone</td>
<td>48 - 1479</td>
<td>6 - 155</td>
<td>5 - 412</td>
<td>24 - 221</td>
</tr>
<tr>
<td>Sand</td>
<td>5 - 1047</td>
<td>1 - 5017</td>
<td>4 - 2971</td>
<td>22 - 7759</td>
</tr>
<tr>
<td>Granite</td>
<td>76 - 1380</td>
<td>4 - 98</td>
<td>103 - 240</td>
<td>25 - 525</td>
</tr>
<tr>
<td>Clay</td>
<td>6 - 477</td>
<td>7 - 1621</td>
<td>4 - 11</td>
<td>11 - 1865</td>
</tr>
<tr>
<td>Fly ash</td>
<td>6 - 522</td>
<td>7 - 670</td>
<td>30 - 159</td>
<td>56 - 773</td>
</tr>
<tr>
<td>Lime stone</td>
<td>6 - 518</td>
<td>1 - 26</td>
<td>1 - 33</td>
<td>5 - 148</td>
</tr>
<tr>
<td>Gypsum</td>
<td>70 - 807</td>
<td>7 - 807</td>
<td>1 - 152</td>
<td>59 - 881</td>
</tr>
</tbody>
</table>

1.6.5. Out door air as the source of radon

Outdoor air usually acts as a diluting factor, due to its normally low radon concentration, but in some cases, it can act as a real source. The radon concentration in outdoor air is mainly related to atmospheric pressure, and (in case of non-perturbative weather) it shows a typical oscillating time pattern, with higher values during night.

Quite high radon concentrations in the outdoor air have been reported near substantial radon sources, such as mine tailings or in the case of particular weather conditions, such as thermal inversion or very low precipitation.

Ambient air over oceans has very low values (0.1 Bq/m³) of radon concentration, due to the minimum presence of radium in the sea water and the high solubility of radon in water at low temperatures. Therefore radon concentration in outdoor air of islands and coastal region is generally lower than in continental countries.
Taking into account recent measurements, the mean value of outdoor radon concentration adopted by UNSCEAR in its last report has been changed from 5 to 10 Bq/m³ for continental areas and somewhat less in coastal regions.  

Typical radon sources and entry routes are shown below in fig. 5-
1.7. Exhalation

The term $^{222}\text{Rn}$ exhalation or flux marks the passage of $^{222}\text{Rn}$ from the soil/building material to the indoor environment. A measure of exhalation is given by the exhalation rate, which is the number of atoms leaving the soil per unit surface area per unit time. The parameters like atmospheric pressure, temperature and wind force greatly influence the radon exhalation rate. Rainfall or snow cover can lead to temporal sealing of the soil surface, whereby $^{222}\text{Rn}$ accumulated beneath the sealing, and the exhalation rate is minimized. The exhalation rate is largest under a moderately damp soil\textsuperscript{61}. Under these conditions, only small pores are filled with water, resulting in a high exhalation rate. The larger pores are still dry, so relatively large migration distances are possible\textsuperscript{62}.

1.8. Remedial and preventive measures to reduce indoor radon

The main sources of indoor radon are: soil, building materials and, in some cases, water from deep wells. Experimental work carried out at international level has shown that radon from soil represents generally the most important sources of indoor radon\textsuperscript{63-70}. The actions to reduce indoor radon concentration are mainly oriented to limit the ingress of radon from soil. This goal can be reached by removal of the source, diverting the radon before entering the building and/or using barriers between the soil and the living space. The main methods available to reduce the ingress and the concentration of indoor radon can be summarized as follows:

* Reduction of radon entry from soil through depressurisation of sub floor space;
* Increasing the building ventilation rate with a consequent increase of radon removal;
* Increasing the resistance of building to radon entry by sealing the floor (or the walls, in case of building materials with high exhalation rate);
* Removing the radon source which is applicable only to water supply.

1.8.1 Depressurisation

Normally the pressure inside a building is less than in the soil gas and this causes soil gas to enter the building. If however, the pressure differential between the soil and the building is reduced the radon entry is decreased. In order to obtain soil depressurisation, a zone of subjacent soil is maintained at a lower pressure difference than the building, by means of a small fan or by a vented stack.

Different methods are available to obtain such soil depressurisation\textsuperscript{71-73}. If the building has a concrete floor, a fan can be used to suck air from beneath the floor and vent it to atmosphere. Usually a radon sump is built which consists in a hole in the ground with a suitable fan connected to it sucking from the hole and generating a negative pressure in the hole.

1.8.2 Ventilation

Increasing the ventilation rate to reduce the radon concentration is one of the easiest methods available. Moreover, a knowledge of the radon source is not required. There are, however, practical difficulties in determining how much the ventilation rate should be increased and how it can be supplied in order to be acceptable by the occupants.

1.8.3. Sealing

In the foundations of a dwelling, usually many openings exist through which soil gas can penetrate. These openings include junctions between walls and floor, gaps between floor and slab sections, openings left for service entries, etc.
The remedies, which can be applied, are to fill the gaps and openings by using sealing materials like epoxy resin. A rigid sealant is not convenient, since the cracks are in constant motion due to climate changes, shrink-swell cycle etc. As an alternative a plastic cover can be applied on the floor taking care to seal accurately the junctions between wall-floor, etc.\textsuperscript{74}.

1.9. A Brief Review about Radon Studies

In the recent past, environmental scientists have been expressing concern about the radiation hazards from radon and its decay products inside dwellings.\textsuperscript{75,76} It has been recognized that radon daughters are the probable causative agents of the high levels of lung cancer found in Uranium miners. The international agencies including i] International Agency for Research on Cancer (IARC), ii] International Commission on Radiological Protection (ICRP), iii] United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and iv] World Health Organization (WHO) are involved in radon studies.

A larger number of indoor radon surveys carried out in several countries\textsuperscript{77-79} reveal the extremely large variation in the radon levels in the houses, covering a range from a few Bq m\textsuperscript{-3} to 100,000 Bq m\textsuperscript{-3}. Almost all the countries in the world are engaged in the measurement of radon levels in the environs of different geological areas. These include radon measurements in soil, rocks, atmospheric air and the dwellings. Numerous measurements of the activity concentrations of $^{222}\text{Rn}$ and its short lived decay products in different countries have been published in recent years.\textsuperscript{80-86} Many groups in India too are engaged in the study of indoor radon measurements in dwellings for health risk assessments and its control. A large group of workers at BARC have been actively
engaged for radon mapping all over the country. Apart from BARC, presently, several active groups of workers are engaged in radon studies in India. They are from Guru Nanak Dev University, Amritsar, Aligarh Muslim University, Regional Engineering College (REC), Kurushetra, Defence Laboratory, Jodhpur, North Eastern Hill University, Shillong, Garhwal University, Gauhati University, Guwahati, Osmania University, Hyderabad. There are also numerous groups to study radium content in soil samples and radon exhalation rates from soil samples.

1.10. Aims and Objectives of the Present Studies

Exposure to radon in the home and workplace is one of the main risks of ionizing radiation causing lung cancer. In order to reduce this burden it is important that national authorities have methods and tools, based on solid scientific evidence, to formulate sound public health policy. The public needs to be aware of radon risks and the means to reduce and prevent them.

In 1996 WHO published a report containing several conclusions and recommendations covering the scientific understanding of radon risk and the need for countries to take action in the areas of risk management and risk communication.

There are many groups now performing measurements or planning measurement programs. It is important for these different groups to follow consistent procedures to assure accurate and reproducible measurements and to enable valid intercomparison of measurement results from different studies. Although results of indoor radon level measurements in various parts of North Eastern Region of our country have been
reported, the information about the contributions to radon levels from different sources like soil, rocks, different types of building materials is still scanty in literature. Nero et al. (1990) estimated that soil contributes more than 90% of Rn in houses. Thus the main objectives of the present studies will be to estimate indoor radon concentration and soil radon concentration and soil radon exhalation rates in different areas of Pathsala, Barpeta, Noonmati, Numaligarh and Duliajan of Assam. From these observations, estimation of the following can be made of:

- Indoor radon inhalation dose.
- Seasonal variation of the above mentioned dose if any.
- Correlation between radium content in soil and soil radon exhalation rates if any.

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26
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