

AN OVERVIEW OF RADON

1.1 Introduction

The increasing awareness about the harmful effects of nuclear radiation demands that all the sources of nuclear radiation must be monitored. Most radiation we receive in the normal course of events is composed of: (a) cosmic rays, (b) gamma-rays and (c) radon gas. Cosmic rays originate from the sun and the outer space. Typical equivalent dose of cosmic rays at sea level is $0.03 \mu\text{Sv}\cdot\text{h}^{-1}$ (UNEP, 1985). 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}K , ^{238}U and ^{232}Th series etc. Half-lives of the above radioactive elements in the earth are very long. The magnitude of the dose received by an individual from these sources depends on the type of rocks and surrounding soils. The estimated equivalent radiation dose from these sources (gamma-rays) is reported to be about 0.35 mSv per year (UNEP, 1985).

Amongst the 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}Rn alone (Matiullah et al, 1993b). After its discovery in 1900, radon was regarded as having curative powers and was added to everything from toothpaste to hair cream. People were not aware of its deadly health hazards. This invisible silent killer was pursuing the people in a secret way so as to avoid being noticed, causing a plague of lung cancer. The link between lung cancer and radon was first shown in 1950s in uranium miners, exposed to high levels of the gas during their work (Durrani and Ilic, 1997). The experience gained in the uranium miners provided, not only information on health risk, but also the initial tools for understanding its sources, behavior, measurement techniques and control in the more general environment.

Radon comes from the radioactive decay of uranium in the soil. Radon has no immediate health effects, but it in turn gives rise to short-lived (solid particulate) daughter products that are the main health risk (Evans, 1980). A colorless, odorless, radioactive gas radon that seeps into people's houses from the underlying soil, builds up to higher levels and may cause the occupants to die from lung cancer many years

later (Davies and Forward, 1970). This is, however, not the only reason why radon is an interesting object of research: radon is also an excellent (tool of research in a variety of fields) tracer of resources such as deeply buried uranium deposits (Durrani and Ilic, 1997; Khan and Qureshi, 1994). To estimate the general risk posed by indoor radon and to use it as a helping tool, a systematic approach has to be adapted. Besides monitoring indoor radon concentration levels, its entry sources have to be identified. In addition to this, understanding and modeling of radon transport is also essential. These issues have been addressed in the following sections.

1.2 Physical and Chemical Properties of Radon

^{222}Rn is a colorless, odorless, tasteless, non-flammable and α -radioactive gas. Therefore it can not be detected with the human senses. Its melting point is $-71\text{ }^{\circ}\text{C}$ and boiling point is $-61.8\text{ }^{\circ}\text{C}$. Radon has the highest density of $\sim 9.96\text{ kg.m}^{-3}$ and is about ten times heavier than air. Being a noble gas, it has greater ability to migrate freely through soil, air, etc. (Matiullah et al, 1993a).

Radon has three important isotopes. These are: (i) ^{222}Rn (called radon, belongs to ^{238}U decay series); (2) ^{220}Rn (called thoron, belongs to ^{232}Th decay series); (3) ^{219}Rn (called actinon, belongs to, ^{235}U decay series). Scientifically, radon is known to be ^{222}Rn , the most abundant isotope of the element radon (Nazaroff and Nero, 1988). In the literature the terms radon and ^{222}Rn are often used interchangeably. This approach has been also adopted in the present work. ^{219}Rn has a relatively low abundance in the earth's crust, i.e. only about 0.7%, and has the shortest half life of ~ 4 seconds. Because of its very short half-life, ^{219}Rn usually disappears soon after its production. ^{220}Rn is also not able to travel far (i.e. it decays before reaching the earth's surface due to its-short half-life of 55.5 seconds), and can often be eliminated from the monitoring system by introducing filters or other delaying techniques. The most important isotope of radon is ^{222}Rn . Its half-life is 3.82 days and can move a substantial distances from its point of origin (Durrani and Ilic, 1997). That is why only ^{222}Rn is generally considered as a health hazard when estimating risk factors from exposure to radon. There are no sinks for radon, and it is estimated that only negligible quantity escape to the stratosphere (Gingrich, 1983). As a result, the ultimate and sole fate of ^{222}Rn is transformation or degradation through radioactive decay.

radon daughters (in whatever proportion) in one liter of air, which will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy during its decay, down to ^{210}Pb (relatively long lived). In other words if daughters are in equilibrium with radon then approximately 100 pCi.l^{-1} (3700 Bq.m^{-3}) of radon is 1 WL.

WL is calculated by counting potential alpha energy as shown in Table 1.1. Assume that 100 pCi (3.7 Bq) of ^{222}Rn is present in one liter of air. All of its daughters will also show the same activity if they are in secular equilibrium with radon. Using the relation ($\lambda_i N_i = 3.7 \text{ Bq}$), the number of atoms of each daughter can be calculated. Multiply this number with the total alpha's energy that the daughter and its descendants would emit until the long-lived member ^{210}Pb is produced. Then total α -energy is found to be $1.3 \times 10^5 \text{ MeV}$ (Durrani, 1993).

Table 1.1: Required data for calculation of Working Level

Nuclide	α energy (MeV)	Half life	Number of atoms	Ultimate α energy (MeV)	Total α energy (MeV)
^{218}P	6.00	3.05 min	977	6.00+7.69	0.134×10^5
^{214}Pb	0	26.8 min	8580	0+7.69	0.659×10^5
^{214}Bi	0	19.7 min	6310	0+7.69	0.485×10^5
^{214}Po	7.69	10^{-6} min	0.0008	7.69	0.006125×10^5
Total:					1.3×10^5

For the sake of ease and simplicity, people often measure the concentration of radon gas in order to estimate the WL of radon daughters. Such estimates are subject to error because the daughters of radon may not be in equilibrium with radon due to the plate-out of daughters on solid surfaces and ventilation effects. In such cases "Equilibrium Factor (F)" needs to be considered, which is defined as follows:

$$F = \frac{EER}{C_{Rn}} \quad (1.1)$$

$$EER = F \times C_{Rn} \quad (1.2)$$

Where C_{Rn} is the measured radon concentration and EER is the Equilibrium Equivalent Radon concentration. Equilibrium Equivalent concentration of Radon (EER) of a non-equilibrium mixture of short-lived radon daughters in air is "the activity concentration of radon in radioactive equilibrium with its short-lived

daughters which has the same potential-energy concentration as the actual non-equilibrium mixture". A commonly assumed equilibrium ratio is 0.5 (i.e., the decay products are halfway toward equilibrium), in which case 3700 Bq.m⁻³ would correspond to 0.5 WL. However, equilibrium ratios vary with time and location, and ratios of 0.3 to 0.7 are commonly observed. The human exposure to radon daughters is expressed in units of Working Level Month (WLM). One WLM is equivalent to 1 WL exposure for 170 hours (i.e. an occupational month). In the environmental situations, exposure to 1 WL for a year (8760 h) would correspond to an integrated exposure of 51 WLM (Tufail et al., 1992).

1.5 Radon and Risk

The principal health effect attributed to inhalation of radon and radon daughters is lung cancer. The connection between radon and lung cancer in miners has raised concern that radon in homes might be causing lung cancer in the general population, although the radon levels in most homes are much lower than in most mines. Intensive epidemiological investigations have been realized on occupational health risk but analysis related to the non-mining population (general public) is comparatively rare. The general population is exposed to much lower levels of radon progeny than were the uranium miners. Uranium miners were also exposed to other materials including cigarette smoke that could have influenced lung cancer induction. Other differences relate to work state (e.g., breathing rate), nature of aerosol distribution, population characteristics such as age, sex and relative lung physiology. Thus, extrapolation of the results for uranium miners to the general population is complex and highly uncertain.

Scientists often use mathematical models to describe or predict effects at doses that have not been well studied. There are three common models used for projecting the relationship between the dose of a cancer-causing substance and the effect (development of cancer). (1) The linear model assumes that as you increase the dose, you will see a linear increase in the effect, (2) The threshold model assumes that there is no effect at all with a very low dosage, but as the dosage increases, you reach a certain threshold at which an effect is seen, (3) The quadratic model assumes that as you go to lower doses the risk decreases faster than the dose. In the quadratic model, the risk increases approximately as a square of the dose. All three models assume that there is no effect at a zero dose and all three show the same health risk at high doses

because they are all based on the available data such as the underground miner studies. The dose-effect relationships for the high doses are reasonably well established. The problem is to make a connection between these data and lower dose levels as most people are exposed to, much lower concentrations than the miners.

The predictive risk model of lung cancer accepted by the NCRP is based on data in high exposure of underground miners. The extrapolation (projection) to low-level exposure is supported by epidemiological studies of lung cancer in non-smokers. Following assumptions were made to develop these models.

- a) No lung cancer occurs before the age of 40 years.
- b) There is a latent period of 5 to 10 years between the exposure and the occurrence of cancer.
- c) The lung cancer probability for a given exposure decreases with the increase in age.
- d) No contribution to lung cancer is assumed after the age of 85 years.
- e) The appearance rate for lung cancer for a single exposure is highest when age at exposure is highest.
- f) The median age associated with manifestation of lung cancer is around 60 years for non-smokers and 50 plus for smokers.

The lifetime lung cancer risk, R , is calculated in the following manner.

First the annual risk is determined, subsequent to an annual exposure of 1 WLM at t_0 .

$$A(t, t_0) = CN(t_0)e^{-\lambda(t-t_0)} \quad (1.3)$$

Where $A(t, t_0)$ = The probability of cancer induction at age t ($t > 40$) due to a single annual exposure at t_0

C = The risk coefficient per year per WLM

$N(t_0)$ = Number of WLMs of exposure at age t_0

λ = Constant accounted for decrease in rate of risk due to repair, cell death or unspecified mechanism ($\lambda = \ln 2/20 \text{ yr}^{-1}$)

Now the lifetime risk, R , at the age of t_m for multiple exposures is obtained by summing the annual risk as follow;

$$R = \sum_{t_0}^{t_m} \sum_t^{85} A(t, t_0) \quad (1.4)$$

Where $t = 40$ to 85 for $t_0 < 35$, and $t = (t_0 + 5)$ to 85 for $t_0 > 35$.

1.6 EXCESS LUNG CANCER RISK

The excess lung cancer risk is defined as the occurrence of excess deaths per million persons per year (MPY) due to the lung cancer as a result of exposure to radon and its daughter products. The risk coefficient, defined as the number of lung cancer cases per MPY per working level month (WLM), is determined from the epidemiological data of the occupationally exposed mine workers. A limited data is available for lung cancer cases due to the indoor radon exposure (Field; 2001; Field et al., 2000; Pershagen et al., 1992; ICRP-60, 1990; Field and Becker, 2001). According to this data, the risks appear to be consistent with the earlier estimates that are based on the data of mine workers. Therefore, to assess the population lung cancer risk due to the indoor radon exposure, the data for mine workers is usually considered. A number of models for calculations of the lung cancer risk due to the indoor radon exposure have been reported in the literature (BEIR-IV, 1988; NCRP, 1984; EPA, 1986 & UNSCEAR, 1988).

The excess lung cancer risk per MPY as a function of the indoor radon concentration level is shown for the risk coefficients of the listed agencies in Fig. 1.1. As can be seen, there is a wide variation amongst the estimated values of the excess lung cancer risk. The excess lung cancer risk calculated using the UNSCEAR upper limit of the risk coefficient is the highest. On the other hand, the lower limit of the risk coefficient recommended by EPA yields the lowest excess lung cancer risk value. This variation is mainly due to the use of different assumed parameters in the models proposed by the above-mentioned agencies whose validity is not certain because of the non-availability of the required information regarding the deaths due to the lung cancer caused by indoor exposure to radon and its daughters. Therefore only approximate estimates of the lung cancer risk are possible with the help of these models.

It may be noted here that the estimates of lung cancer risk per WLM published by UNSCEAR and EPA pertain to Western populations. To arrive at proper risk projections, one must take the mathematical models derived from epidemiological

studies of miners and apply them to the case of indoor exposures for a population with defined vital statistics. Because both tobacco usage and radon cause lung cancer (Field, 2001), the risk per WLM vary from population to population.

A comprehensive calculation of risk for any population of a specific area would involve knowledge of age-specific lung cancer rates and overall mortality rates in the population. If such data is not available for population of specific area (e.g. most area of Pakistan) then it would be advisable to calculate the excess lung cancer risk for such areas using the risk coefficients reported by UNSCEAR and EPA.

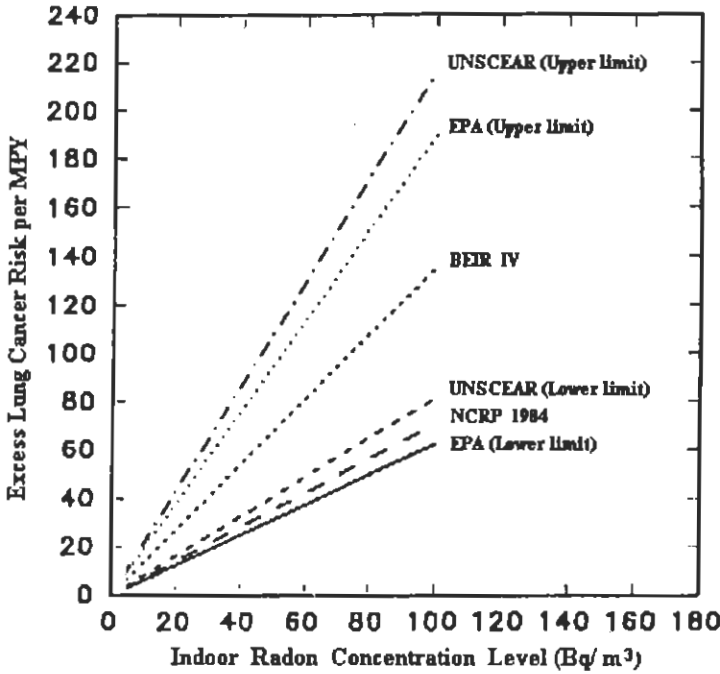


Figure 1.1: Excess lung cancer risk as a function of indoor radon level

The excess lung cancer risk is calculated using the following relation (Matiullah et al., 2003).

$$\text{Excess Cancer Risk} = 0.5 \times 0.8 \times \text{Risk Factor} \times \text{WLM} \tag{1.5}$$

Where 0.5 is the equilibrium factor and 0.8 is the occupancy factor (i.e. the fraction of time spent indoors)

1.7 Indoor Radon Sources

The primary sources of radon and radon daughters in buildings are the soil adjacent to the building, potable water supplies and building materials (Musa, 2003). Radon in outdoor air may also enter a structure as the air is exchanged. This input is usually

more than balanced by the loss of radon to the outdoors (since indoor air concentrations are usually higher than those outside the structure). The other source of radon entry into a building that has been examined is natural gas usage. However, this source is usually very small in comparison with the others. Characterization of the indoor sources of radon requires consideration of the rate at which radon is generated in the source materials and its modes of transport through various materials which will be discussed later in this chapter.

As mentioned earlier, radon is directly produced from radium in the ^{238}U decay series which is found everywhere in varying trace amounts in the earth's crust, therefore the major contributor to the indoor radon concentrations is the soil beneath the house (Kerry, 1982). Radon in the soil gas near buildings can move into houses through cracks or holes in the foundation. This phenomenon provides a partial explanation for the observed higher radon levels in basements and on ground floors as compared to upper stories. The other key factor may be the normal air circulation patterns.

Building materials generally contribute fairly little to the total indoor radon concentration, except when the radium content in it is above the normal values. All building materials are derived from soil and rock that contain trace amount of radioactive nuclides occurring in the earth's crust. Many of the building materials such as bricks, wallboard or concrete are sufficiently porous and allow the radon to enter into the indoor air. Materials which are not derived from the earth's crust, such as wood, tend to have a very low radium concentration (Nazaroff and Nero, 1988). Consequently radon concentrations in dwellings partly depend on construction practices and materials used.

Where water is in direct contact with mineral particles that contain radium, radon can be implanted in water by alpha recoil (Akerblom, 1994). Radon gas is soluble in non-polar solvent but mildly soluble in cold water. If the radon concentration in air is about 3 Bq.m^{-3} , the concentration in water will be 1.5 Bq.m^{-3} at 0°C (Musa, 2003). When ground water passes through soil and rocks containing significant amount of radon gas, it can be dissolved and then transported by the water. When radon-containing water is heated or aerated, a large part of the dissolved radon is released during activities such as showering, and using dishwasher or clothes washer. The risk associated with radon in drinking water is usually not considered to be great despite the high concentrations sometimes found. It has been shown that the most

significant dose arising from radon in potable water is a result of inhalation of radon released from the water (Suomela and Kahlos, 1972), as opposed to doses to the stomach from drinking water.

Fortunately, not all the radon produced from radium in the soil and building material can migrate and enter into a home. Some of the radon atoms are trapped within the grains of soil and are not able to escape to pore spaces (Semkow, 1990). From the un-trapped radon atoms, some are absorbed in ground water and some diffuse through the soil. Besides some other parameters, the radon concentration in soil gases and dwellings mainly depend on the emanation and exhalation rate of radon respectively.

1.8 Emanation

In mineral grain, ^{226}Ra decays to ^{222}Rn by emitting an α -particle. Most of the radon produced remains within the grain. The small fraction of it escapes to the pore spaces either promptly or within a few days before it decays, depending on the grain size and location of its parent in grain (Duenas et al., 1997). The main mechanism of escape is recoil energy of its atoms during the α -decay of ^{226}Ra and diffusion through grain as shown in Fig. 1.2. The ratio of the escaped radon to the radon produced in the grain is called emanation coefficient denoted by (E), and is known to be in the order of 0.2–0.3 (Durrani and Ilic, 1997) for common constituents of building material (e.g. sand).

The amount of radon emanated to pore spaces depends on the concentration of ^{226}Ra in rock, the spatial distribution of ^{226}Ra within the mineral grain and moisture contents in pores (Sasaki et al., 2004; Edsfeldt, 2001). Mostly, slight differences in ^{226}Ra concentrations in the soil result in greatly varying ^{222}Rn concentrations. This disproportional variation of radon is due to inhomogeneous distribution of ^{226}Ra in grains. A large fraction of ^{226}Ra and ^{230}Th (precursor of ^{226}Ra) is accumulated near or at the surfaces of mineral grains, which results in a greater probability for ^{222}Rn atoms to be catapulted into the pore space. The increase of soil moisture will absorb the recoil energy partly, and the probability for an atom of ^{222}Rn remaining within the pore space is enhanced.

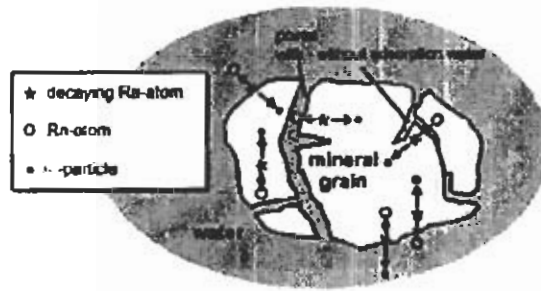


Figure 1.2: Sketch of emanation processes in dependence on location of ^{226}Ra atoms and soil moisture contents

1.9 Exhalation

The term ^{222}Rn exhalation or flux marks the passage of ^{222}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 a temporal sealing of the soil surface, whereby ^{222}Rn is accumulated beneath the sealing, and the exhalation rate is minimized. The exhalation rate is largest under a moderately damp soil (Sun, 2004). 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 (Sasaki et al., 2004).

1.10 Mechanism of radon transport

One of the central questions of radon research is: how to predict the indoor radon concentration of a building? In principle, given sufficient structural information about the porous medium and underground processes responsible for forced flow of radon, such a prediction is possible using models based on well known physics. The parameters that quantify the structure of the porous medium (Van der Spoel, 1998) are the porosity (volume fraction of the medium occupied by pores, ϵ), the fraction of water saturation (volume fraction of pores occupied by water, m) and the intrinsic permeability k (m^2). Porosity is usually expressed as the total porosity, which is the sum of the aeration and water-filled porosity of medium. In soil and building materials diffusion and advection are responsible for radon transport. The transfer of

^{222}Rn from one place to the other due to the concentration gradient (∇C) is called diffusion (Nazaroff and Nero, 1988). For wet soils the diffusion distance ($S = (D\tau)^{1/2}$, τ is the mean life of radon and D is the diffusion coefficient) is only some centimeters, whereas in dry soils it can reach about 1.5 m (Fleischer et al., 1980). The movement of ^{222}Rn due to the pressure gradient between the air in pore space and ground surface is called advection. During advective transport, ^{222}Rn is moved passively in the flow of a medium, which can be seeping water or soil-gas, like CO_2 or CH_4 . (See Fig. 1.3). Based on advective transport the range of a ^{222}Rn transport in soil (Fleischer, 1998) can reach up to 100 m or more.

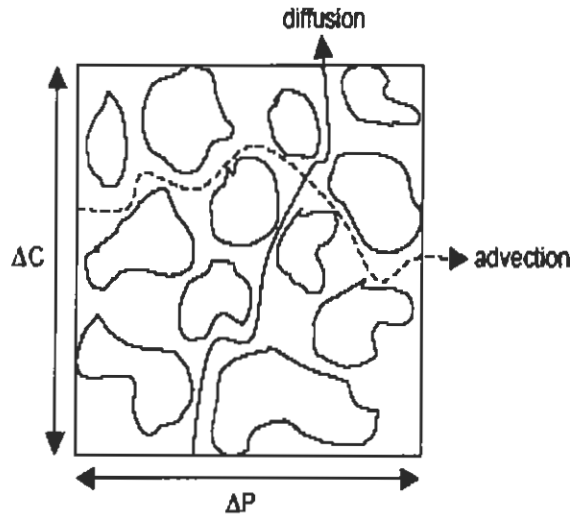


Figure 1.3: Diffusive and advective transport of radon

The activity fluxes ($\text{Bq}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) of radon are given by Fick's law (diffusion) and Darcy's law (advection).

$$\bar{j}_{d,a} = -(1-m)\epsilon D_a \nabla C_a \quad (1.6)$$

$$\bar{j}_{d,w} = -m\epsilon D_w \nabla C_w \quad (1.7)$$

$$\bar{j}_{a,a} = -C_a \frac{K}{\mu} \nabla P \quad (1.8)$$

Where the subscripts d, a on the fluxes denote diffusion and advection whereas the subscripts a, w refer to the air and water phase. D_a and D_w are diffusion coefficients

($\text{m}^2.\text{s}^{-1}$) in air and water, K (m^2) is the intrinsic permeability; μ (Pa.s) is the dynamic viscosity of air; C_a and C_w are radon concentrations (Bq.m^{-3}) in air and water phase; P (Pa) is the pressure disturbance field (relative to absolute pressure).

Inside pours, the bulk production rate S ($\text{Bq.m}^{-3}.\text{s}^{-1}$) of radon is

$$S = E\rho_b\lambda R \quad (1.9)$$

Where E is the emanation coefficient; ρ_b is the bulk dry density; λ is the decay constant and R is the radium activity per unit dry mass (Bq.kg^{-1}). To investigate transport mechanism, mass balance equation for each phase of this multi-phase system can be written as:

$$(1-m)\varepsilon\frac{\partial C_a}{\partial t} = \nabla \cdot ((1-m)\varepsilon D_a \nabla C_a) + \frac{K}{\mu} \nabla P \cdot \nabla C_a - (1-m)\varepsilon\lambda C_a + E\rho_b\lambda R \quad (1.10)$$

$$m\varepsilon\frac{\partial C_w}{\partial t} = \nabla \cdot ((1-m)\varepsilon D_w \nabla C_w) - m\varepsilon\lambda C_w + E\rho_b\lambda R \quad (1.11)$$

$$\rho_b\frac{\partial C_s}{\partial t} = -\rho_b\lambda C_s + E\rho_b\lambda R \quad (1.12)$$

In the above equations diffusion and advection terms are assumed negligible in solid phase and advection term is assumed negligible in water phase. Concentrations of radon in different phases are related as follow (Van der Spoel, 1998):

$$C_w = LC_a \quad (1.13)$$

$$C_s = k_a C_a$$

Where L is the Oswald coefficient and k_a is the surface adsorption coefficient. Using Eq. (1.13) we can combine the three single phase equations to one equation for radon in air phase as follow:

$$\beta\frac{\partial C_a}{\partial t} = D\nabla^2 C_a + \frac{K}{\mu} \nabla P \cdot \nabla C_a - \beta\lambda C_a + E\rho_b\lambda R \quad (1.14)$$

$$\text{With} \quad \beta = (1-m+Lm)\varepsilon + \rho_b k_a \quad (1.15)$$

$$D = ((1-m)D_a + mD_w L)\varepsilon \quad (1.16)$$

Where β and D are the partition corrected porosity and bulk diffusion coefficient respectively. Solution of this three dimensional differential equation gives us radon concentration in pores air. Using special boundary conditions, solution of this equation for a closed system is given in Chapter 7.

1.11 Radon Measurement Techniques

After over viewing properties, origin, transport and health effects of radon, the next step is the monitoring of radon. As mentioned earlier radon decay results in promptly decaying progeny therefore the detection and measurement of radon can be performed either directly on radon itself also called “radon alone measurement” or indirectly through its daughters. Since radon and most of its progeny decay by emitting α , β or γ radiations, therefore radon detection and measurement can be performed through the detection and measurement of these radiations. Many techniques are available for measurement of radon. These are classified into two main categories:

1. Instantaneous/active techniques
2. Time integrated/passive techniques

1.11.1 Active Techniques

Instantaneous/Active techniques are those that require power for their operation and are used normally for short term measurements. The instantaneous techniques are based upon methods in which grab sample of the air is collected at an instant of time, followed by measurement of radon concentration through its α -particle activity. These techniques are briefly described in the following subsections:

1.11.1.1 Lucas Cell (Scintillation Method)

It is one of the oldest techniques. The instrument consists of glass vessel internally coated with scintillating material such as ZnS, except from the bottom end surface, which is transparent and coupled to a photomultiplier tube (PMT). Its shape is usually cylindrical but can be of any shape depending on the type of PMT employed to count the scintillation produced. Since alpha particles can travel only short distances in air before stopping, the volume of the Lucas cell is often limited to a few hundred cubic centimeters. A sample of air is drawn into the cell, and the α -particles produced from radon decay cause scintillations in ZnS, which are detected by the photomultiplier tube and generate an electric pulse.

1.11.1.2 Ionization Chamber

In this technique the chamber is filled with filtered radon. The alpha particles emitted in the decay of radon and its daughters will ionize the air in the chamber. In the presence of applied voltage the electrons and ions are drifted towards their respective electrodes. The resulting current is a measure of the quantity of decayed radon atoms. Counting is started after the establishment of equilibrium between radon and its decay products and the radon concentration can be obtained from the number of pulses.

1.11.1.3 Surface Barrier Detector (SBD)

SBD is a p-n junction diode operated under reversed biased conditions. The alpha particles from radon decay enters the depletion region and creates electron hole pairs, electron flow in one direction, holes in the other and total number of electrons collected can form an electronic pulse whose amplitude is proportional to the energy of the radiation.

1.11.1.4 Two Filter Method

This technique is used to measure both radon and its daughter's concentrations. Air is passed through first filter so that radon daughters are removed, and allow the air to pass through a long decay chamber so that the daughters grow again and are collected on the second filter. The filters are counted separately; radon concentration is determined from the second filter and its daughter concentration from the first filter.

1.11.1.5 Working Level Method

In this method, an air sample is pumped through a filter over a given time period. Alpha particles emitted from radon daughters deposited on the filter are counted using SBD. A modern instrument that can be used for this purpose is the Mensura Working Level Meter. This operates by sampling air from the environment at a constant rate. It has a mobile battery-operated power supply.

The active measurement techniques are not so beneficial to accurately measure the radon levels because of temporal variation in radon level due to the temperature and pressure gradients.

1.11.2 Passive Techniques

In order to obtain results which incorporate the effects of seasonal, weather and environmental conditions on radon concentrations in dwellings, it is very important to carry out measurements over a long period of time. It is the long-term average in dwellings that determines the damage to human's health. The use of integrating devices is the most practical way of obtaining a long term average radon concentration. Hence these techniques are preferred for survey work in order to determine the annual average radon concentration of a specific building. These techniques are briefly discussed:

1.11.2.1 Thermoluminescent Technique

Thermoluminescence is the property whereby certain substances are capable of storing energy that can be released in the form of light when the substance is heated. These materials are called TLD chips. As TLDs are sensitive to alpha, beta and gamma radiation, a procedure has to be adopted to determine the alpha contribution only. Two TLDs are mounted in an inverted cup and placed in the ground. One of the TLDs is wrapped in a foil that will exclude all alpha particles, that is it must be made radon tight, but the beta and gamma radiations are not excluded. After a certain time the TLDs are retrieved and analyzed by heating those to 300 °C in the appropriate read out equipment. When a chip is heated, light is emitted, which is proportional to the amount of radiation present. The contribution from alpha radiation can be determined by subtracting the intensity of the energy in first TLD (exposed to only Beta and Gamma radiation) from second TLD (exposed to Alpha, Beta and Gamma radiation) and hence the radon activity is measured (Hussein, 1997).

1.11.2.2 Electrets

Electrets ion detectors which contain an electro-statically charged Teflon disk are widely used for long-term radon measurement. Ions generated by the decay of radon strike and reduce the surface voltage of the Teflon disk. By measuring the voltage reduction, the radon concentration can be calculated.

1.11.2.3 Charcoal Canister Technique

This technique is used for rapid radon survey. Activated charcoal has a capacity for adsorbing and retaining radon. In this technique a canisters containing activated

charcoal are exposed to air for few days, so that radon enter in the canister. The amount of radioactive material collected in the activated charcoal is evaluated by gamma spectroscopy or by liquid scintillation counting. The problem with this technique is that it needs a sophisticated electronics for the analysis and secondly the results cannot be reproduced even in the same location for similar experimental conditions.

1.11.2.4 Etched Track Detectors

All the above stated passive techniques require extensive electronics and sophisticated laboratory facilities. This renders them not suitable for use in remote and rugged areas. Besides this, the instruments used, in all the above passive techniques are expensive and not easily available (Khan and Qureshi, 1994). The most widely used method for long monitoring period is based on materials known as Solid State Nuclear Track Detectors (SSNTDs)/etched-track detectors. The technique is simple to use and relatively inexpensive. Several detector materials have been developed. The most suitable for indoor radon measurements appears to be CR-39 because of its good sensitivity, stability against environmental factors and high degree of optical clarity (Matiullah et al, 1993a). Therefore, SSNTD-based method was used for indoor radon measurements in the present study. Detail analysis and working principle of this technique will be dealt in the next Chapter.

To detect the radon gas alone in a given environment, the instrument should have mechanism to separate the radon gas from its particulate daughter products and to allow just radon to enter into the sensitive volume of the detector. Several configurations have been developed which use etched track detectors to measure indoor radon concentrations; few are discussed below.

1.11.2.4.1 Membrane Permeation Samplers

The dosimeter is schematically shown in Fig. 1.4a. Here the permeable filter closes the open end of the cup (Durrani and ilic, 1997). The enclosure excludes the condensed alpha emitters, and the filter area and thickness are designed to exclude unwanted ^{219}Rn ($\tau_{1/2} = 3.96$ s) and ^{220}Rn ($\tau_{1/2} = 55.6$ s) without unduly diminishing ^{222}Rn ($\tau_{1/2} = 3.82$ d), along with the daughters that are produced after the ^{222}Rn enters the detection space. The filter is made of a porous material such as fibre glass, microporous paper, or a plastic such as polyethylene or PVC (10 μm thick).

1.11.2.4.2 Plastic Bag Permeation Samplers

The permeation sampler is shown in Fig.1.4b. This permeation sampler is made from a heat-sealed plastic bag (filter) made of polyethylene. There are two CR-39 detector foils and aluminized polycarbonate degraders face the detector foils to optimize the detector responses and to make their surface conductive. The polyethylene bag protects the detector from humidity, dust, thoron and radon daughters (Matiullah, 2000). The advantages of such a type of dosimeter are: (i) simple heat sealing and hence low cost, (ii) small size and fast sampling time, (iii) high radon permeability and (iv) elimination of water vapors. In addition, most of the radon dosimeters have a response which depends on the atmospheric pressure, since the sensitive volume depends on the range of alpha particles, which changes with pressure. In contrast, the plastic bag sampler with polycarbonate degraders has little dependence on the atmospheric pressure, since the degrader is not the air but the plastic foil.

1.11.2.4.3 NRPB radon dosimeter

The NRPB radon dosimeter is shown in Fig. 1.4c. It is designed by the National Radiological Protection Board (UK). It consists of two polypropylene parts: a circular base with a recess to keep the detection element in place and a domed circular upper section with an internal circular base-retaining strut. The detector element uses a piece of CR39 plastic that registers the alpha particle tracks from the decays of radon and its daughter products in an enclosed volume. The overall dimensions of the assembled dosimeter are; a diameter of about 6 cm and a maximum depth of 2 cm. The two parts fit quite tight in order to exclude moisture and radon daughters. Radon enters through the small gap between the two halves. It is a passive radon detector to measure the time integrated radon gas concentration in the immediate environment of the detector (Howarth, 2002).

The etched track radon dosimetry consists of different working phases (Fig. 1.5). The influence of the different parameters such as the type of detector, etching conditions and track evaluation procedures on the dosimeter response is covered in Chapter 2.

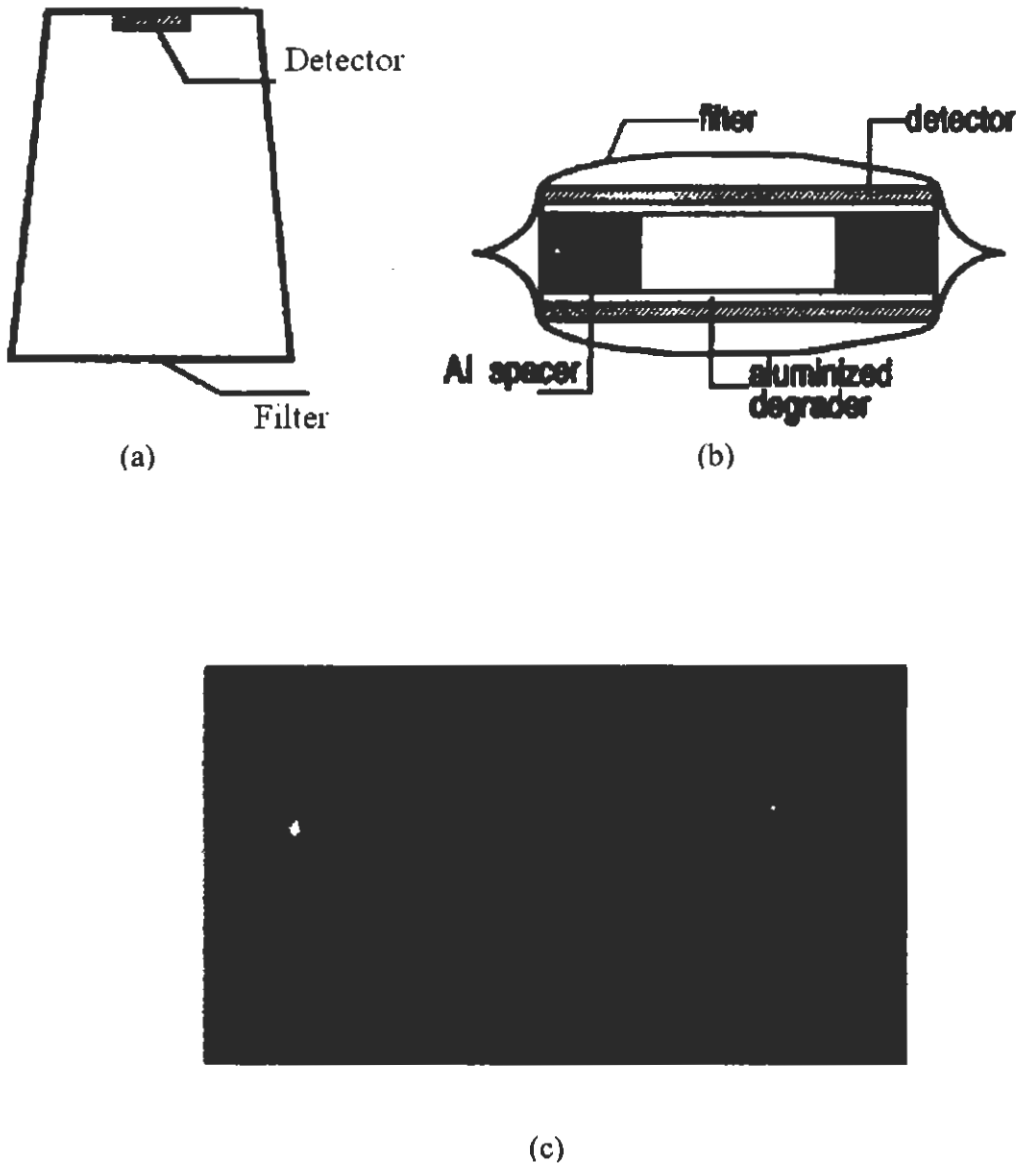


Figure 1.4: Radon monitoring devices based on etched track detectors (a) filter permeation sampler (b) Plastic bag permeation sampler (c) NRPB radon dosimeter

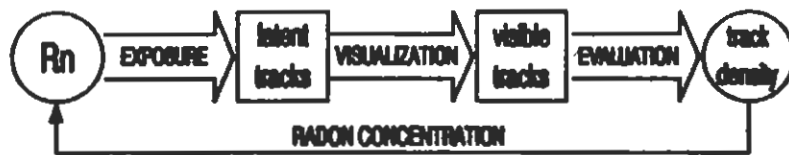


Figure 1.5: Schematic representation of the main processes involved in radon detection and evaluation by an etched track radon dosimeter (Matiullah, 2000)

1.11 References

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