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A Study related to Radiation Exposure with special reference to Radon

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Abstract:
In the present context, we have studied the radiation exposure from different radiation sources with special reference to radon. Thoron and Radon account for maximum exposure which is mainly background radiations. Other background radiations which add to radiation exposure are terrestrial, space and internal radiations.In the present study, we have discussed radon in detail with specific sub topics like radiation exposure, radon emanation, radon isotopes and its half-life, radon-element properties, radon occurrence in nature, history of radon gas,world history of radon, indian scenario, world scenario, basic quantities and measurement units, advance techniques, online gas monitors, scintillation-based radon monitor-srm, thoronmonitor and itsapplication.

Keywords: *Radiation Exposure, Radon Emanation, Half-life, Epidemiology, Diffusion co- efficient, Dosimetric Quantities*

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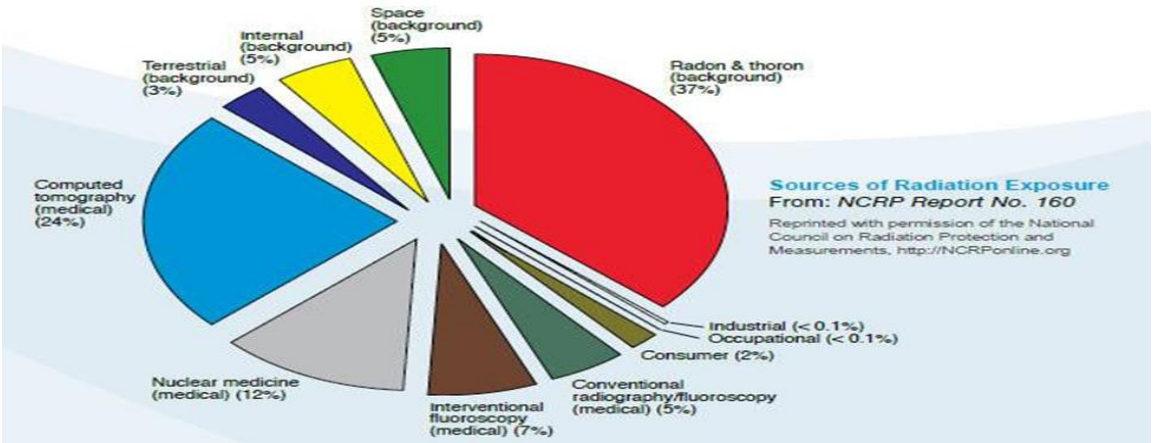
I. INTRODUCTION

1. Radiation Exposure

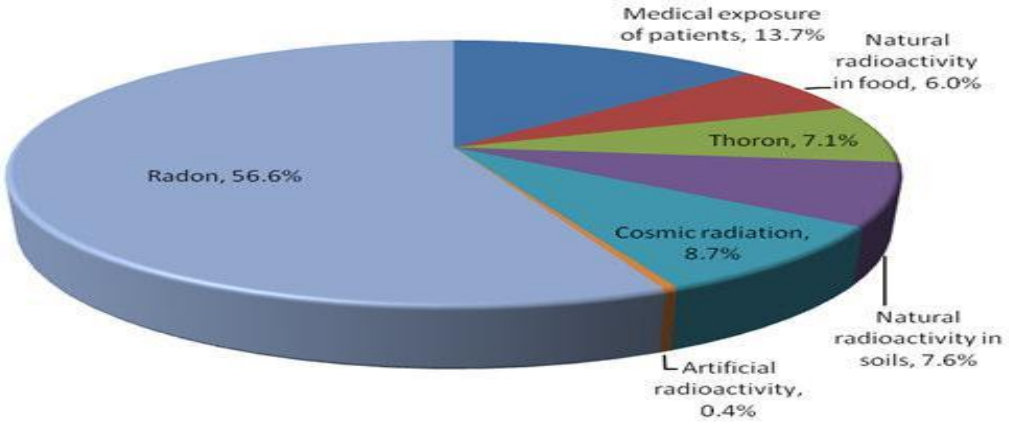
We are subjected to radiation exposure from different radiation sources. Thoron and Radon account for maximum exposure which is mainly background radiations. Other background radiations which add to radiation exposure are terrestrial, space and internal radiations. The total radiation exposure pie chart is provided below from which we can analyze the sources of exposure and their contribution.

Fig 1: Sources ofradiation exposure



However the elements of contributing radiation are provided in the pie chart below:-

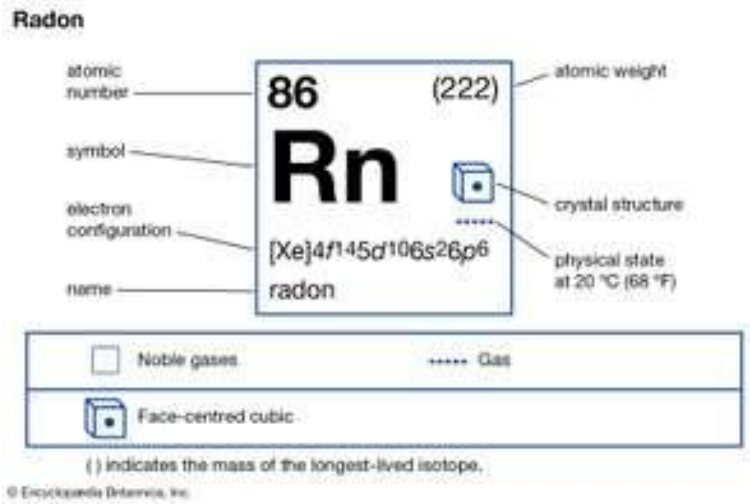
Fig 1.2: Elements contributing to radiation



1.1 Radon Emanation:

Radon isa radioactive gas that emanates from rocks and soils and tends to concentrate in enclosed spaces like underground mines or houses. Soil gas infiltration is recognized as the most vital (important) source of residential radon. Other sources of radon like building materials and water extracted from wells, are also important in some circumstances. It is a major contributor to the ionizing radiation dose received by most of the population [1].

Radon (Rn), Chemical element (originally called radium emanation.), a heavy radioactive gas of Group 18 (noble gases) of the periodic table, It is a colourless, odourless and tasteless gas that occurs naturally as the decay product of the elements radium, uranium and thorium. Due to noble (or inert) gas, it is inactive chemically and combines with other substances only under extreme conditions. Radon is dense the heaviest known gas and also considered a health hazard due to its radioactive radiation. It is 7.5 times heavier than air and more than 100 times heavier than hydrogen. The radon gas liquefies at −61.8 °C (−79.2 °F) and freezes at −71 °C (−96 °F). On further cooling, solid radon glows with a soft yellow light that becomes orange-red at the temperature of liquid air (−195 °C or −319 °F) [2].



Radon is rare in nature as a result its isotopes are all short-lived (temporary)and also because of radium (source of radon) is a scarce element. The atmosphere contains traces of radon near the ground as a result of seepage from soil and rocks, both of which contain minute quantities of radium. (Radium comes as a natural decay product of uraniumpresent in various types of rocks.)

By the late nineteen eighty, naturally occurring radon gas had come to be recognized as a potentially serious health hazard due to its radioactive decay of uranium in minerals, especially granite, which generates radon gas that can diffuse through soil and rock and enter in houses through basements (radon has a higher density than air) and through water supplies derived from wells (radon has a significant solubility in water). The gas will accumulate within the air of poorly ventilated homes. The decay of radon produces radioactive “daughters” (polonium, bismuth, and lead isotopes) that can be ingested from well water or can be absorbed in dust particles

and then breathed into the lungs. Exposure to high concentrations of this radon and its daughters over the course of many years can greatly increase the risk of developing carcinoma (lung cancer) [3]. Indeed, radon is now thought to be the largest cause of lung cancer among non-smokers in the United States.

1.2 Radon isotopes and its half-life:

Natural chemical element (radon) consists of three isotopes, one from each of the threenaturalradioactive-disintegration series (the uranium, thorium, and actinium series).

Radon-222(3.823-day half-life), which is discovered in 1900 by German chemist Friedrich E. Dorn, the longest-lived isotope, arises in the uranium series [4]. The name radon is usually reserved for this isotope to differentiate it from the other opposite two natural isotopes, known as thoron and actinon, which is originate from the thorium and the actiniumseries respectively.

Radon-220 (51.5-second half-life) was first observed in 1899 by the British scientists Robert B. Owens and Ernest Rutherford (also known as thoron), who noticed that some of the radioactivity of thorium compounds could be blown away by breezes in the laboratory.

Radon-219 (3.92-second half-life), which is associated with actinium (also known as actinon), was found independently in 1904 by German chemist Friedrich O. Giesel and French physicist André-Louis Debierne. Radioactive isotopes having masses ranging from 204 through 224 have been identified, the longest-lived of these being radon-222, which has a half-life of 3.82 days. All the isotopes decay into stable end-products of helium and isotopes of heavy metals, usually lead.

Radon atomspossessa particularly stable electronic-configuration of eight electrons in the outer shell, which accounts for the characteristic chemical inactivity of the element. Radon, however, is not chemically inert. For example, the existence of the compound radon difluoride, which is apparently more stable chemically than compounds of the other reactive noble gases, krypton and xenon, was established in 1962. Radon's short lifetime and its high-energy radioactivity cause difficulties for the experimental investigation of radon compounds.

When a mixture of trace amounts of radon-222 and fluorine gas is heated to approximately 400 °C (752 °F), a non-volatile radon fluoride is formed [5]. The intense α-radiation of mill curie and curie amounts of radon provides sufficient energy to allow radon in such quantities to react spontaneously with gaseous fluorine at room temperature and with liquid fluorine at −196 °C (−321 °F). Radon is also oxidized by halogen fluorides such as ClF_3, BrF_3, BrF_5, IF_7, and $[NiF_6]^{2-}$ in HF solutions to give stable solutions of radon fluoride. The products of these fluorination reactions have not been analysed in detail because of their small masses and intense radioactivity. Nevertheless, by comparing reactions of radon with those of krypton and xenon it has been possible to deduce that radon forms a difluoride, RnF_2, and derivatives of the difluoride [5]. Studies show that ionic radon is present in many of these solutions and is believed to be Rn^{2+}, RnF^{+}, and RnF_3^{-}. The chemical behaviour of radon is similar to that of a metal fluoride and is consistent with its position in the periodic table as a metalloid element.

1.3 Radon-Element Properties:

- Atomic number (number of protons in the nucleus): 86
- Atomic symbol (on the periodic table of the elements): Rn
- Atomic weight (average mass of the atom): 222
- Density: 9.073 grams per liter
- Phase at room temperature: Gas
- Melting point: (- 95) degrees Fahrenheit (- 71 degrees Celsius)
- Boiling point: minus 79 F (- 61.7 C)
- Number of isotopes (atomic number are same); 33 whose half-lives are known with mass numbers 196 to 228
- Most common isotope: Rn-222 (half-life of 3.823 days)
- Electronic configuration; $(Xe)4f^{14}5d^{10}6s^{2}6p^{6}$

1.4 Radon occurrence in nature:

Radon is present in the air nearly everywhere, so we can said that everyone breathes in radon every day. According to the National Cancer Institute, low level of radon is harmless. But people who inhale high levels of it are at an increased risk of developing carcinoma(lung cancer) [3].

According to the Environmental Protection Agency (EPA), radon is the No. 1 cause of lung cancer among non-smokers and is associated with approximately 21,000 lung cancer deaths a year; 2,900 of those deaths occur among people who have never smoked [6].

The harmful effect of radon, however, had been known since the 1500s, where mine workers, who worked in badly ventilated mines often were exposed to high quantities of radon. And it was found that these people

developed breathing problems and pined away to what was back then known as 'mountain sickness'. In 1879, this 'mountain sickness', which many mine workers suffered from, was identified as lung cancer by Herting and Hesse.

The presence of radon in indoor air was first documented in 1950, and ever since 1970, governments around the world has set up agencies to analyse radon concentrations in their households. In UK, radon leaks were analysed by The National Board of Health in 2001 and recommendations about doorstep measurements, and reduction methods were worked out from that time continuously.

Upon cooling and getting to a solid state, the gas glows in yellow colour. And as the temperature lowers, the gas shines in an orange-red colour. Basically, radon seeps into constructions as the resultant of underground decaying uranium, radium or thorium ores. Plus it also varies greatly in amounts from region to region [2].

Radon in high level is dangerous, however; on the other hand, very small amounts of it are also used in treating certain types of cancer by established and verified hospitals.

Thoron and Uranium are two most common radioactive element on the earth and they have been around since the formation of earth. Because Uranium is relatively plentiful in nature and have a long half-life (billions of years) so Thorium, Uranium and their decay product Radium and Radon will therefore continue to occur for tens of millions of years at almost the same concentrations as they do now. Since the source of radon generation mechanism is within earth (because of uranium decay products) so radon will never go away.

II. REVIEWS:

2.1 History of Radon Gas:

Radon isn't a commercially produced gas just for the purpose of benefiting out of it. The gas is formed due to certain natural processes i.e. with the breakdown (decay) of uranium under the soil. The element radon was first discovered by Fredrich E. Dorn, a German physicist in the year 1900. While he was working with the element radium (studying radium's decay chain), he named it as radium emanation [7].It is however the Pierre and Marie Curie (1899) who had already observed such an emission that remained radioactive but only for around a month. Radon was the fifth radioactive element that was discovered after uranium, radium, thorium, and polonium.

The same year, Owens and Ernest Rutherford along with Robert B noticed continuous emissions from thorium oxide that remained radioactive for a couple of minutes. This radiation was called as emanation(emanare in Latin meaning expiration or to elapse) [8]. Later, it was officially named as ThoriumEmanation *(*Th Em). Rutherford in the year 1901 had demonstrated the radioactivity of emanations however credited Curies for the element's discovery. André-Louis Debierne noticed similar radiations from actinium naming it ActiniumEmanation(Ac Em) [9].

However, in the year 1910, Sir William Ramsay and Robert Whytlaw-Gray were the ones to isolate radon and also determined its density suggesting that the radiation might contain some elements from the category of noble gases [10]. In the contact with some particular substance a fresh name got suggested for the emanation as Niton (Nt) because the gas caused an unusual glow. In the year 1912, International Commission for Atomic Weights accepted this name. However, in the year 1913, International Union of Pure and Applied Chemistry (IUPAC) along with The International Committee for Chemical Elements acted upon and finalized the names radon (Rn), thoron (Th), and actinon (An). After all of this, radon and radon fluoride obtained its first synthesized compound in the year 1962 [11].

2.2 World History of Radon:

During the middle of 19th century (1924–1932), it was founded that radon was the cause of high lung cancer incidence. In 1951, researchers at the university of Rochester N.Y. pointed out that the lung cancer health hazard was from the alpha radiation dose delivered by the radon decay products that deposited in the respiratory tract. The findings of the BEIR Committee Report VI, which was based on epidemiological studies in different groups of mines in the 1950's and 1960's and on laboratory studies, showed that from 60,000 miners over 2,600 developed lung cancer where only 750 were expected [12].

Since 1998, the epidemiological study conducted in Iowa US, showed beyond any reasonable doubt that radon decay products cause lung cancer among women who lived at least twenty years in their homes. This paper will cover early radon measurements in soil, building material, ground water and in different air environments such as in the atmosphere, caves spas, underground mines and in residential indoor air environment [13].

Radon is a natural radioactive noble gas that is present in trace amounts almost everywhere on the earth, being distributed in the soil, groundwater and in the lower atmosphere. We know well that low levels of radon can be found in drinking water however, radon released during water usage adds small quantities to indoor radon concentration. The purpose of the current review is to summarize recent literature and evaluate the

health effects of radon. Radon is an established human lung cancer based on human epidemiological data supported by experimental evidence of mutagenesis studies in cell culture and laboratory animals.

2.2.1 Indian scenario:

A continuous and long term measurement of radon in groundwater was carried out using alpha-counter, alpha logger, emanometer and plastic detector, LR-115 type II. Radon concentration level is being monitored daily at Amritsar, Punjab and other stations in Kangra valley, Himachal Pradesh India.

Singh et al., 1999 have studied radon in groundwater wells in the year 1997 at Amritsar, India using zinc-sulphate(Ag) detector. Significant increase in radon concentration in water with the depth of the wells has been observed. These are correlated with the seismic events that occurred in Northern India during the period of study [14].

Ramola et al., 1999 have measured radon in the drinking water of Dehradun City. The recorded radon concentrations in water extracted using hand pumps were found to vary from 27 to 154Bql^{-1} with an average of 67 Bql^{-1}, while radon concentrations in water from tube wells were found to vary from 26 to 129 $Bql^{-1}$with an average of 59 Bql^{-1}[15].

Virk et al., 2000 have reported that they have carried out radon monitoring at Palampur and Dalhousie stations in Kangra and Chamba valleys using emanometry since 1992 under Himalayan Seismicity programme of Government of India.

Choubey et al., 2000 have reported that radon concentration in groundwater in Himalayan region was found to vary from 0.4 to 887 Bql^{-1}. The radon values were recorded highest within the springs exhausting through metamorphic rock, granite, mylonite, etc. The high level of radon concentration in fracture-joint and fault-lineament spring was associated with quantitative relation of rock surface area to water volume and uranium mineralizationwithin the shear zones present in the close vicinity of fault and thrust.

Mahesh et al., 2001 have measured the ^{222}Rn concentrations in groundwater samples from coastal Karnataka and Kaiga region by emanometry method. The concentration of ^{222}Rn in open well water was found to vary in the range 0.14 to 25.4 Bql^{-1} and that in bore well water in the range of 0.22 to 197.0 Bql^{-1}.

Choubey et al., 2003 have measured the radon concentration in ground water of Doon valley in Himalaya. Radon concentration in tube wells and hand pumps varies from 25.4 to 92.5 Bql^{-1} with an average of 53.5 Bql^{-1}. A significant direct correlation between level of radon concentration and depth of the wells suggesting that level of radon concentration increases with drilling depth in areas consisting of sediments of younger Doon gravels [16].

Sonkawade et al., 2004 have measured the radon levels in tube-well water samples at the Nuclear Science Centre, Delhi using Alpha Guard. Radon levels were found to vary from 1645 to 3869 Bqm^{-3}.

Bajwa et al., 2005 have reported the radon concentrations in the drinking water of Punjab and Himachal Pradesh. The radon concentration was found to vary from 1.0 to 48.0 Bql^{-1}.

Rajashekara et al., 2007 have measured the activity concentration of radon in ground water and surface water samples of two major rivers of coastal Karnataka, namely, Kali and Sharavathi using an Alpha Guard. ^{222}Rn concentration in bore well water was found to vary in the range of 0.91 to 15.86 Bql^{-1}, for open well water it ranges from 0.33 to 9.70 Bq l^{-1} in the catchment areas of Kali River.

Shiva Prasad et al., 2007 have estimated the ^{222}Rn concentrations in potable waters from the Bangalore using the emanometry method and it was found to vary from 5.3–283.4 Bql^{-1} with a mean value of 87 Bql^{-1}. The effective dose was found to vary from 42.6 to 2280.2 μSvy^{-1} with a mean value 702.5 μSvy^{-1}. The effect of boiling water showed a drastic reduction in the ^{222}Rn concentration.

Prasad et al., 2008 have measured the radon concentration in ground water of Budhakedar area of Tehri Garhwal, India and it was found to vary from 8 to 3.05 $kBql^{-1}$[17].

Hunse et al., 2010 have reported a study conducted by the Central Ground Water Board and found high levels of radon in groundwater of Bangalore and it is found to vary from 55.96 to 1189.30 Bql^{-1}.

Badhan et al., 2010 have measured the radon concentration in ground water at Jalandhar using radon meter (RAD7). The level of radon concentration in drinking water has been found to vary from 2560 to 7750 Bqm^{-3}[18].

Somashekara and Ravikumar 2010 have measured radon activity in the Varahi and Markandeya command areas using RAD7. The measured ^{222}Rn activities in groundwater samples of Varahi command area ranged between 0.2 and 10.1 Bql^{-1}. In contrast, the recorded ^{222}Rn activities in groundwater samples of Markandeya command area was found to vary from 2.21 to 27.3 Bql^{-1}.

Ramola et al., 2014 have measured radon activity level along the main central thrust (MCT) in Uttarkashi, Budhakedar, Ukhimath and Healang regions of Garhwal Himalaya, India. The large variations in the radionuclide distribution have been estimated along the MCT. The ^{226}Ra, ^{232}Th and ^{40}K contents in MCT area varies from 8 ±1 $BqKg^{-1}$, 285 ± 28 $BqKg^{-1}$ with an average of 64 $BqKg^{-1}$, 7 ± 1 $BqKg^{-1}$to 136 ± 15 $BqKg^{-1}$ with an average 69 $BqKg^{-1}$and 115 ± 18 $BqKg^{-1}$ to 1588 ± 162 $BqKg^{-1}$with an average 792 $BqKg^{-1}$respectively. The

radon exhalation rate and radon concentration in the soil of study area varies from 2.20×10^{-5}BqKg^{-1}h^{-1} to 3.2 10^{-5}BqKg^{-1}h^{-1} and 287Bqm^{-3} to 417 Bqm^{-3} respectively[19].

2.2.2 World scenario:

Prichard H.M 1987 has reported that it was reasonable to assume an increment of one pCil^{-1} of radon in indoor air to 10,000 pCil^{-1} of radon in the water supply. Makinde 2005 has discussed that the radon released from domestic water typically contributes less than 2% of total indoor radon and describes the health risks from radon in domestic water and the efforts made within the United States to regulate radon in drinking water.

McGregor and Gourgon 1980 have reported that the concentration of radon in tap water supplies varied from 47 nCil^{-1} to 370 nCil^{-1} at Nova Scotia. Transfer efficiencies of 37% to 70% were observed.

Shapiro 1988 and Alabdula′aly 2011 have reported that, in the United States, several wells had been found to contain more than 37,000,000 Bqm^{-3} of dissolved radon in the water. This radon can be released to the indoor air in the course of using water for normal household activities.

Henshaw et al., 1993 have reported the ^{222}Rn in domestic tap water at 504 locations throughout UK. Most values were close to 1 Bq1^{-1} and none were above the limit suggested by UK National Radiological Protection Board of 100 Bq1^{-1}[20].

Yu et al., 1994 have reported that the radon concentration of 3.56 kBqm^{-3} and 0.806 kBqm^{-3} was found in natural mineral water and in tap water samples respectively. Moreover, it was also shown that the annual effective doses due to inhalation of radon emanated from tap water and flushing water was negligible when compared to the total annual effective dose for indoor radon in Hong Kong [21].

Savidou et al 2011 have reported the measurement of radon concentrations in about 80 samples from drawn from bore wells and taps. The concentration ranges from background concentrations to 170 Bql^{-1}. 23% of water samples of Northern Greece have the radon concentration level exceeded 50 Bql^{-1}.

Salonen et al., 2002 have reported that the various aeration techniques such as spray nozzle aeration, packed tower aeration and diffused bubble to remove radon from water, which was carried out during 1997-1999 with the European Commission (CEC) under the supervision of the Directorate- General XII Radiation Protection Research Unit.

Almeida et al., 2004 have analyzed ground water from a coastal area of Rio de Janeiro state, for ^{226}Ra, ^{228}Ra, ^{222}Rn, ^{238}U and physico-chemical parameters. Detectable ^{222}Rn concentrations (>3 Bq l^{-1}) were found only in two samples.

Segovia et al., 2007 have determined the radon in groundwater of Mexico using liquid scintillation technique. Groundwater radon levels were in generally low, having maximum of 11.3 Bql^{-1}.

Somlai et al., 2007 have reported the ^{222}Rn concentration in water samples in Hungary and have found an average of 5.56Bq l^{-1}. The radiation dose originating from the consumption of drinking water by adults does not reach the value of 0.1 mSvy^{-1}.

Cosma et al., 2008 have studied the radon concentrations in 1511 samples of all types of water sources in Romania using Lucas cell and it was found to varies from 0.5 to 129.3 Bql^{-1} with an average of 15.4 Bql^{-1}.

Khattak et al., 2011 have measured the radon concentration in 36 drinking water samples from taps, bore wells and deep tube wells of Peshawar, Pakistan using RAD7 device. Radon value in this region was found to varies from 8.8 to 18.2Bql^{-1}.

Oner et al 2013 have measured the radon concentration in four spas used for therapy, drinking and irrigation purposes in the Amasya basin in Turkey. The observed radon concentration values ranged from 0.11 to 10.71 Bql^{-1}.

III. MEASUREMENT AND TECHNIQUES:

For measurements and model formulation for ^{222}Rn, ^{220}Rn and their decay products, various quantities are used. Some of the quantities can be measured directly by experiments and some of them, theoretical, are useful for model formulations. These quantities and their corresponding units are described below [22].

3.1 Basic quantities and measurement units:

Radioactivity (A):

The radioactivity is the rate of disintegration of a radioactive element. The standard international (SI) unit is the Becquerel (Bq) which corresponds to number of disintegrations per second. Curie (Ci) is another conventional unit for radioactivity. 1 Ci is equal to 3.7 X 10^{10} Bq.

Specific Radioactivity (Q):

It is defined as the amount of radioactivity per unit mass of the radioactive material. The SI unit of this quantity is Bq kg^{-1}. In case of radon studies, it refers to radium content (*R*) and is defined as the activity of radium present per unit mass of the sample.

Activity concentration (C):

It is defined as the activity of the radionuclide present per unit volume of sample. The SI unit for activity concentration is Bq m^{-3}. For a porous sample such as soil, pore space concentration refers to activity present per unit pore volume. Similarly, for dissolved activity in water, the activity concentration is activity present per unit volume of water, also expressed in units Bq l^{-1}.

Radon emanation factor (E):

It is defined as the fraction of radon produced in the grains of porous matrix, which is released to the pore space of the matrix and is available for further transport. It is a dimensionless parameter. It is also referred to as radon emanation co- efficient or radon emanating power.

Porosity (n):

It is defined as the ratio of pore volume to the bulk volume of the porous matrix. It is a dimensionless parameter. It can be estimated from bulk density and density of solid grain. In case of pore spaces partially filled with moisture, partition corrected porosity (n_e) is used in formulation of models.

Diffusion co- efficient (D):

It is the proportionality constant in the Fick's law of diffusion stated as

$$F = -D\frac{\partial C}{\partial Z} \quad \text{..... (1)}$$

Where,F is the diffusion flux (Bq $m^{-2}s^{-1}$) and $\frac{\partial C}{\partial Z}$is the concentration gradient in z direction (Bq m^{-4})

Hence diffusion coefficient is the flux per unit concentration gradient. Its SI unit is $m^2\ s^{-1}$. Molecular diffusion coefficient (D_m) refers to the diffusion coefficient in free air. The diffusion coefficient for a porous matrix (D_s) refers to the product of molecular diffusion coefficient and tortuosity of the matrix, where tortuosity accounts for the diffusion in the curvilinear (tortuous) paths. The effective diffusion coefficient (D_e) is defined as the product of porosity and the diffusion coefficient of the matrix.

Radon mass exhalation rate (J_m):

It is defined as the rate of radon exhalation per unit mass of the sample. Its SI unit is Bq $kg^{-1}\ s^{-1}$. It is normally used for assessing the radon exhalation potential of powder samples such as soil, cement etc. This quantity is also used to estimate radon emanation factor. For this purpose, the sample thickness must be much smaller than radon diffusion length in the matrix.

Radon surface exhalation rate (J_s):

It is defined as rate of radon exhalation per unit surface area of the sample. Its SI unit is Bq $m^{-2}s^{-1}$. It is normally used for assessing the radon exhalation potential of samples with regular geometry, such as bricks, tiles, concrete blocks etc. This quantity may be extrapolated using an appropriate model to estimate the radon emissions from building walls.

Radon Flux (F):

It is defined as the radon emission per unit area of the surface of porous matrix like soil, wall etc. Its SI unit is Bq $m^{-2}\ s^{-1}$. This quantity is the measure of source term for radon in environment and is very useful for predicting the radon concentration in environment through dispersion and dilution models.

3.2 Special Quantities:***Potential Alpha Energy (PAE):***

The potential alpha energy (MeV) of an atom in the decay chain of ^{222}Rn / ^{220}Rn is the total alpha energy emitted during decay of this atom through the decay chain to ^{210}Pb in the case of radon progeny or ^{208}Pb in the case of thoron decay products.

Potential Alpha Energy Concentration in Air (PAEC):

The potential alpha energy concentration of any mixture of short lived radon or thoron decay products is the sum of the total potential alpha energy of all daughter atoms per unit volume of the air. The historical unit of this quantity is Working Level (WL) and the SI unit is J m^{-3}. Often, it is also expressed in MeV l^{-1}. The WL is defined as that concentration of short- lived radon decay products in any combination which would potentially produce 130,000 MeV of alpha particle kinetic energy per liter of air. A more exact computation of the potential alpha energy for 1 WL concentration is obtained from 100 $pCil^{-1}$ (3.7 Bq l^{-1}) of ^{222}Rn gas or 0.275 Bq l^{-1} of ^{220}Rn gas in equilibrium with its daughter products. One WL corresponds to 2.08 X 10^{-5} J m^{-3} in SI units. Radon/thoron progeny concentration exposure is often expressed in terms of WLM (Working Level Month); which corresponds to an exposure of 1 WL during a reference- working period of one month (2000 working hours per year/12 months = 170 hrs)[23].

Equilibrium Equivalent Concentration (EEC):

The EEC of radon is equal to that quantity of radon concentration which is in secular equilibrium with its decay products giving equivalent PAEC for the progeny nuclides actually present in the atmosphere. The "Equilibrium Equivalent Concentration" EEC, can be expressed as:

$$EEC=\frac{0.136C_a+0.660C_b+0.488C_c}{1.284} = 0.106C_a+0.514C_b+0.380C_c \quad \text{..... (2)}$$

where,C_a, C_b, C_c are the ^{218}Po, ^{214}Pb and ^{214}Bi concentrations (Bq l^{-1}),

There is a direct linear relation between EEC and PAEC. 1 WL corresponds to 3700 EEC in case of radon and 278 EEC in case of thoron. For direct estimation of EEC, information on C_a, C_b and C_c is required. However, it is difficult to measure C_a, C_b and C_c individually. A simpler approach to estimate EEC is by using the radon gas concentration and the equilibrium factor for a particular environment. The equilibrium factor is defined below.

Equilibrium Factor (F):

It is defined as the ratio of the EEC to the radon concentration in the environment. Although this factor varies depending on the environmental conditions, it has been observed that for typical indoor environment such as a house, the factor does not vary significantly for the case of radon. The global average of the value of *F* for radon in indoor environment is about 0.4. In contrast for the case of thoron, this factor varies significantly even for the same environment. This is mainly due to wide variation of thoron concentration arising from its short- lived nature. ***Hence is not advisable to estimate EEC of thoron using the gas concentration and equilibrium factor.***

3.3 DosimetricQuantities [[13]]:

Absorbed Dose (D_a):

It is defined as the amount of energy imparted by ionizing radiation per unit mass of the matter. The SI unit of absorbed dose is J kg^{-1} and the special name for the unit of absorbed dose is Gray (Gy).

Equivalent Dose (H): It is the averaged absorbed dose to a tissue weighted for the radiation quality using radiation weighting factor (W_R). Mathematically, it can be expressed as

$H_T = \sum W_R D_{T,R}$ ……(3)

Where, H_T is equivalent dose in tissue T, $D_{T,R}$ is the absorbed dose averaged over the tissue or organ T, due to radiation R and W_R is the radiation weighting factor (W_R =1 for gamma radiation and W_R=20 for alpha). The unit of this quantity is Sievert (Sv).

Effective dose (D_E):

It is the average of equivalent dose due to a radiation, to all tissue or organs, weighted using tissue weighting factor (W_T). Mathematically, it can be expressed as

$D_E = \sum W_T H_T$ …… (4)

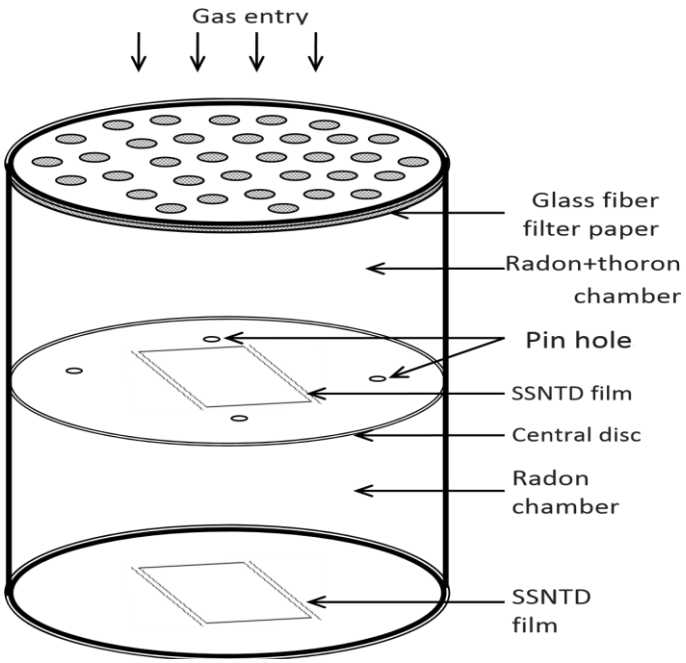
Where,H_T is equivalent dose in tissue T and W_T is the tissue weighting factor. This is the quantity of practical interest. The unit of this quantity is Sievert (Sv).

3.4 ADVANCE TECHNIQUES:

In India, the LR- 115 track detector based twin cup dosimeter has been used for indoor 222Rn and220Rn measurements on a large scale. However, a key issue in this dosimeter is that of arrivingsometimes at a negative 220Rn concentration in the process of calculation using subtraction method.One of the reasons for this unwanted result may be attributed to the assumption of the same entryrate of 222Rn from two faces of the dosimeter. This assumption may not be true always due toreasons like atmospheric turbulence. To overcome this, a new "pin- holes based twin cup dosimeter"has been developed, with single face for entry of 222Rn and 220Rn gases from environment. Thedesign of such dosimeter was possible only because of a newly developed pin- holes based 222Rn - 220Rn discrimination technique and the associated theory. The pin- holes technique is very useful todesign 220Rn discriminator for online radon measuring instrument with optimum response time for222Rn. By selecting a suitable chamber volume and dimension of pin- holes, it is possible to cut off220Rn entry into the chamber volume and allow only 222Rn.

3.4.1. Pin- holes based 222Rn / 220Rn discriminating dosimeter

The new design of this dosimeter system has two compartments separated by a central pin- holesdisc made up of HDPE material, acting as 220Rn discriminator. Four pin holes each with dimension of2 mm length and 1 mm diameter are made in this circular disc. The schematic diagram of thedosimeter system is shown in Fig. The dosimeter has a single entry through which gas enters thefirst chamber namely "radon+thoron" chamber through a glass fiber filter paper (0.56 μm) andsubsequently diffuses to second chamber namely "radon" chamber through pin- holes cutting off theentry of 220Rn into this chamber. Each chamber is cylindrical having a length of 4.1 cm and radius 3.1cm. Chambers are internally coated with metallic powders to have zero electric field inside thechamber volume, so that the deposition of progenies formed from gases will be uniform throughoutthe volume. This design replaces the use of membrane filter with pin holes based discriminator. Iteliminates the possible negative 220Rn concentration previously arrived in some situations, as thesame gas diffuses to both the chambers [[24]].



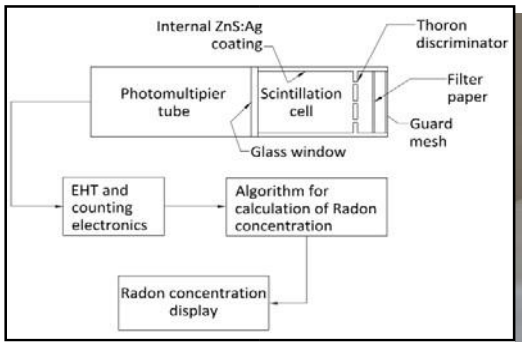
Schematic diagram of the pin holes based dosimeter

3.4.2. Online Gas Monitors

The time- integrated measurement of radon and thoron using passive technique is mainly limited to dosimetric applications. On the other hand, continuous online monitoring yields insight into spatiotemporal correlations, build- up in confined spaces, hourly variations induced by pressure and temperature variations, atmospheric transport, extreme excursions, duration of specific highs and lows etc. While the increased computational capabilities on environmental modeling have given rise to greater needs for real time data, the corresponding developments in networking and data transmissions have made it possible to achieve large scale simultaneous measurements. Such facilities are being increasingly developed as part of systems for earthquake predictions, in uranium mining, environmental monitoring and geophysical research [**13**].

3.4.2.1. Scintillation- based Radon Monitor - SRM: Traditionally, the Lucas scintillation cell is used for one point sampling of radon followed by counting after a delay of 3 hrs. This Lucas cell is same as we may use for continuous radon measurements with the help of an algorithm for calculation of level of radon concentration for each sampling time interval. The algorithm accounts for the fraction of radon decay products contributing to the total counts formed by radon in the current interval and in its preceding intervals. This innovative algorithm for correlating the counts with the radon concentration is based on the theoretical growth and decay equations of radon decay products. Using this algorithm, a portable radon monitor called SRM (Scintillation Radon Monitor), utilizing a ZnSAg based scintillation cell has been developed.

The schematic diagram and photograph of the microprocessor based SRM are shown in Figure below. Radon is sampled into the scintillation cell (150 cc) through a "progeny filter" and "thoron discriminator" eliminating radon progenies and thoron. The thoron discriminator based on "diffusion- time delay" does not allow the short lived thoron ^{220}Rn (half-life 55.6 s) to pass thorough. The alpha scintillations from radon and its decay products formed inside the cell are continuously counted for a user- programmable counting period by the PMT and the associated counting electronics. The alpha counts obtained are processed by a microprocessor unit as per the developed algorithm to display the concentration of radon [**13**].



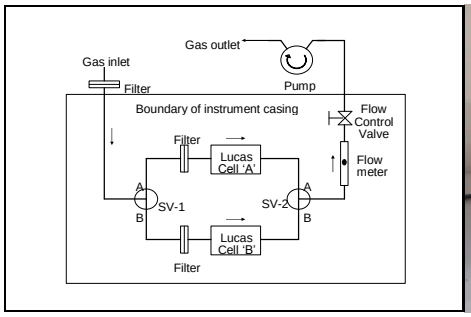
Schematic diagram for portable**Photograph of Portable**

Radon Monitor (SRM) Radon Monitor (SRM)

Considering the limitations on the range of the alpha particles (~6 cm), the dimensions of the scintillation cell have been optimized to achieve high sensitivity (1.2 cph/Bqm^{-3}) with lower detector volume (150 cc).

3.4.***2.2.*** **ThoronMonitor:**

The indigenously developed microprocessor based thoron monitor consists of two Lucas scintillation cells (LSCs) which are coupled to a separate photomultiplier tube with associated pulse preamplifier and scalar. The schematic diagram and its photograph are shown in Figure below. The LSC is a 2" diameter and 3" height cell built in S.S. 316 material with inbuilt two levels of radon- thoron progeny pre- filters for reducing the background contamination. The flow to either LSC is switched by microprocessor at the intervals specified through programmable parameters. During each interval, while one cell counts the background, the other cell measures counts due to both thoron and the background activity. The unit automatically calculates and logs the thoron concentration data in the memory.



Schematic diagram for online Thoron monitor **Photograph of online Thoron monitor**

The problem of radioactive pollution due to radon (and its progeny) is not only a regional but also a global issue and of international concern. Still there are and will be large areas all over the globe where we have little information to support our current estimates of the radon density. Till date there is no central archive of radon flux densities which makes it difficult to model and estimate the average radon flux density distribution. Regional natural radioactive radiation surveys are important for local as well as global estimations of radiation doses.

This issue is very sensitive as it is directly to the public health thus our regional analysis [**13**].

IV. CONCLUSION:

4.1 Based on previous/present study:

Based on the results of epidemiological studies in Europe and North America, World Health Organization (WHO) has brought down the reference level from 200 Bqm^{-3} to 100 Bqm^{-3}. Although radon problem is a major concern in cold climate country and is not expected to be a serious concern in India, there is a need to delineate the variability of radon level in Indian dwellings [25].

The results contrast the findings of previous studies, which suggested that low-level radon exposure is tied to a slightly lower risk of lung cancer (with no statistical difference) or no risk at all, according to the study press release in Science daily.The study is the first to find a statistically significant hormetic effect of low-level radon exposure. The hormetic effect (hormesis) [26] occurs when toxins and other environmental stressors have a

beneficial effect at very low doses. The prevailing idea is that low doses of such toxins stimulate the immune system and the repair mechanisms in cells.The researchers were quite surprised at the previous study of radon. In fact, the goal had been to establish what level of radon exposure was treatto lung cancer risk and to determine a safety zone for radon levels in the respective houses.Ultimately, the researcher found that the chance of developing lung cancer fell below one (the no effect level) at radon exposure within the range of 0-4 pico-Curies per liter [5]. Ninety percent of homes in the United Statesare comes around this level of radon. The EPA recommends that homeowners take action when exposure levels reach over 4 pico-Curies per liter, due to the belief that increasing radon exposure is correlated to developing a greater risk for cancer.

Several times, reports from the United States Environmental Protection Agency (US EPA) have stated how radon causes damage which is almost next to the loss caused due to cigarette smoking. It actually leads to more than 21,000 deaths every year and increasing cases of problems related to lung cancer. This gas is the sixth leading cause of carcinoma (lung cancer) related deaths around the worlds.

Since radon is a second most significant cause of lung cancer, all over the world many research groups working to map the naturally occurring radiation dose rate using different methods, equipments and techniques for indoor, outdoor, dwelling, water, soil, building materials and etc.

4.2 APPLICATION:

Concentrated samples of radon are prepared synthetically for medical and research purposes. Typically, a supply of radium is kept in a glass vessel in an aqueous solution or in the form of a porous solid from which the radon can readily flow. Every few days, the accumulated radon is pumped off, purified, and compressed into a small tube, which is then sealed and removed. The tube of gas is a source of penetrating gamma rays, which come mainly from one of radon's decay products, bismuth-214. Such tubes of radon have been used for radiation therapy and radiography.

Radon was sometimes used by hospitals to treat cancer and other diseases[27]. Hospitals used to produce it themselves by pumping radon from a radium source and sealing it in small tubes called seeds or needles. The seeds were injected at or near the site of the tumour. However, this is no longer in a general practice.

Some researchers have investigated changes in groundwater radon concentrations for earthquake prediction[28][29]. Radon has a half-life of approximately 3.8 days, which means that it can be found only shortly after it has been produced in the radioactive decay chain. For this reason, it has been hypothesized that increases in radon concentration is due to the generation of new cracks underground, which would allow increased groundwater circulation, flushing out radon. The generation of new cracks might not unreasonably be assumed to precede major earthquakes. In the 1970s and 1980s, scientific measurements of radon emissions near faults found that earthquakes often occurred with no radon signal, and radon was often detected with no earthquake to follow. It was then dismissed by many as an unreliable indicator [30]. As of 2009, it was under investigation as a possible precursor by NASA [31].

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