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Radon and Its detection: A Review

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Radioactivity is anatural phenomenon in general. Gaseous forms of radionuclides that present everywhere over the globe are responsible for the radiological dose to livings on Earth. Radon is a primary radionuclide in the radioactive series which exhalate in the atmosphere providing radiation dose to inhabitants. Easy detection and mitigation are essential for quantifying radiological dose to local populations. Active online radon monitors are a better way to estimate radon flux in local areas.

Introduction

Radioactivity is a world-renowned phenomenon. Natural sources of anthropogenic sources make the earth's environment radioactive.Radon and thoron are naturally occurring radioactive substance gases which are widely distributed in Earth’s atmosphere[1].Radon^{222} and its isotope thoron^{220} are the only radioactive gases and both the gases emanate from the earth's crust depending upon the decay series of uranium and thorium which are abundant everywhere on the earth crust. Radon^{222} and thoron^{220} are noble gases but they are radioactive so it becomes important to investigate the radiological impact of radon^{222} and thoron^{220} in the environment[2-5]. Radon^{222} is a decay product of Uranium and thoron^{220} belongs to the decay series of Thorium. Radon^{222} and thoron^{220} contribute up to a 50% fraction of the total dose that is received by the human being. The natural sources of radiation lead up to 70% of global exposure to radiation[6-8]. Radon^{222} has a Half-Life time that is 3.82 days and hence it sustains for a long period in the environment that of thoron^{220}. It has been evident that the radon^{222}is considered the main contributor to dose but we cannot neglect the contribution of thoron^{220}[9]. The emanation of radon^{222} and thoron^{220} depends on many factors like porosity of the soil, humidity, grainsize, and the presence of Uranium content[10]. The study of indoor concentrations of radon and thoron in houses is indeed important such as most of the time humans spent indoors. Thus, most human exposure comes from indoors. In outdoors, radon and its progeny are diluted with other aerosols in the air[11]. A large variation of radon and thoron concentration indoors is due to building materials, surrounding soil types, and topography[12-14]. The naturally occurring radionuclides present in soil and rocks include Ra^{226}, Th^{232}, and K^{40}. Ra^{226} comes from the U^{238} decay series naturally. Radionuclides such as Cs^{137} also present in soil because of weapon testing residual distributed through the air[15]. External gamma dose estimation due to terrestrial radionuclides is also important as it contributes considerably 0.46 mSv.y-1 to collective dose estimation. Most of these doses depend upon the concentration of radionuclides on the earth’s crust, mainly U^{238},

Th^{232}, their decay products and naturally occurring K^{40} present in rocks and soil[16-17]. The accumulation of $radon^{222}$/$thoron^{220}$ in indoor dwellings the major cause of human exposure to indoor radiation which causes health problems and increases in enclosed spaces such as indoors of dwellings, caves, and mines, etc. The indoor concentration/level of $radon^{222}$, $thoron^{220,}$ and their progenies are mainly influenced by the factors like the type of dwellings, subjacent soil, building material, ores, ventilation conditions, and geology of the area. It increases the annual dose of radiation received by human beings. Humans spent their most of time in the indoor environment so the measurement of the indoor concentration of $radon^{222}$ and $thoron^{220}$ becomes essential because of the greater chance of human exposure to radiation in the indoor environment[18]. The recommended limit of the $radon^{222}$ concentration was referred by World Health Organization and it was lowered to 100Bq/m3 from 200 Bq/m3 and suggested that it is the second most carcinogenic element after smoking. $Radon^{222}$ enters the indoor environment from soil and building materials through emanation from the soil matrix and exhalate to the atmosphere. Radioactive gases and radiation come from space that makes the earth's atmosphere radioactive. Anthropogenic activities also free radio-active gases from the atmosphere. The ionizing radiation causes natural background radiation[19]. The radiation level is maintained by radio-active sources present in soil and rocks. The cosmic radiation is significantly higher at the cruising altitudes of aircraft of the jet than on earth's surface. The exposure rates vary throughout the earth and can range more than 100 times the global average. Having significantly long half-life radon is an important radio-nuclide, in the form of gas due to the decay of uranium present in the soil on the earth's surface. Exposure due to inhalation of radon by people living indoors also varies dramatically depending on the local geology[20]. The major radio-nuclide of concern are uranium (U^{238}), potassium (K^{40}), and Thorium (Th^{232}) and their daughter nuclides like radium, radon, and thoron that are intensely radioactive but occur in low concentrations. Primarily these radio-nuclides undergo alpha and beta decay are very hard to detect. However, some of their daughter nuclei are gamma emitters. Despite all that, the emanation of radon gas is the biggest source of natural background radiation. Radon and its progenies contribute to an average inhaled dose of 1.26 mSv annually. Thoron also contributes to annual exposure but its half-life is lower than that of Radon, yet it is fatal to livings due to its high energy alpha emission (<7 Mev)[21]. The diffusion length of the alpha particle is not much (almost 9cm) yet it harms the internal tissues of humans while intake. Ionizing radiation deposits energy when passes through any matter (including living beings) and produces excitation and ionization in the matter. The amount of energy deposited divided by the mass of tissue is known as the absorbed dose. Hence, the damage to the cell of living beings is directly related to the deposited energy. This is why thoron exposure is much viperous than radon exposure to human life. There are some areas in the world (Table 1) having a high absorbed dose rate in the air, which are associated with soil containing Uranium and Thorium. High Uranium abundance leads to more exhalation of radon into the air. Measuring radon has been quite a handful to scientists by eliminating the background noise. Being an alpha emitter, radon has a legitimate characteristic for scintillation-based detection.

Table 1: World-wide range of radiological dose to humans due to radon exposure.

Country	Area	Absorbed Dose Rate (including cosmic and terrestrial radiation in the air (nGy/h))	Reference
Brazil	State of Rio de Janeiro and Espirito Santa Mines Gerais and Goias	100-400 (average 600) Maximum 1400 (Average 2300)	[22]
Egypt	Nile Delta	20-40	[23]
France	Central Region	200-400	[24]
India	Kerala Monazite	200-4000 (Average 1500)	[25]
Iran	Ramsar and AbegarmeMhallat	190-86000 200-4000	[26]
Italy	Lazio Region Campania Region Orvieto Town	Average 175 Average 200 Average 560	[27] [28]
Niue Island	Pacific Island	Maximum 1100	[29]
Switzerland	Tessin, Alps, Jura	100-200	[30]

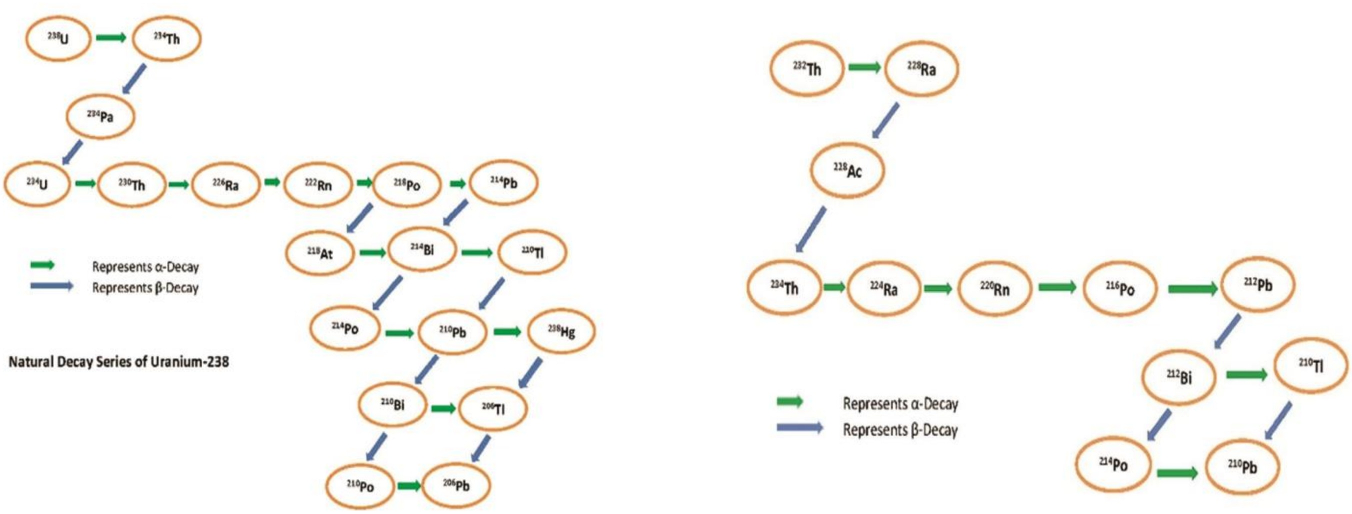

Fig. 1: Natural decay series of Uranium-238 and Thorium-232.

Scintillation cell gas measurement

The most important grab sampling method for the measurement of radon in air is by collecting the gas
in a scintillation flask or cell by sucking the gas through a filter paper. In this method, a sample of air isdrawn into a flask or cell that has a zinc sulfide phosphor coating on its interior surfaces

and issealed. One surface of the cell is fitted with a clear window that is put in contact with aphotomultiplier tube to count light pulses (scintillations) resulting from alpha disintegrations from
the air sample interacting with the zinc sulfide coating. The number of pulses is proportional to theradon concentration in the cell. The cell is counted for about four hours after filling to allow theshort- lived radon decay products to reach equilibrium with the radon gas. Fig. 2 shows the transport mechanism of radon into the atmosphere. Radon emanates from the soil matrix in the Earth's crust by ejecting alpha particles from the radionuclide and recoiling into the air.

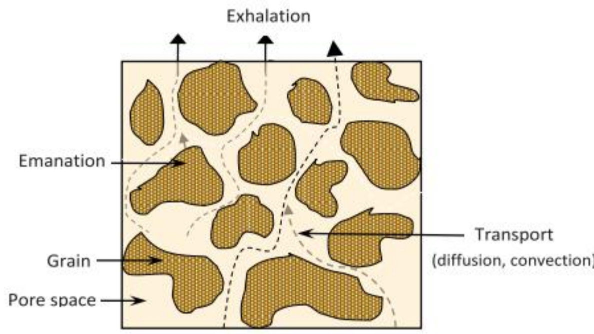

Fig. 2: The process leading to the radon release to the atmosphere.

To measure the radon gas concentration, the alpha activity measured in the sampling cell is computed with respect to the decay of radon gas due to post- sampling delay and build-up of its daughter products. Take the alpha counts for a period of about 500 s, after a post- sampling delay of 16 about 180 min (to achieve equilibrium between Rn^{222} and its decay products Po^{218}& Po^{214}). The Rn^{222} concentration can then be estimated from the counts using the relation [31]:

$$C_{Rn}(Bq.m3) = \frac{C}{3.E.V.\exp(-\lambda t)} \quad (1)$$

where :
C - is the net count rate ,CPS (s^{-1})
E - is the efficiency of counting (fraction)
V - is the volume of the sampler (cm^3)
λ - is the decay constant of radon (s^{-1})
t - is the time delay post-sampling (s)
3 - represents the three alphas (^{222}Rn, ^{218}Po &^{214}Po)

Continuous Radon Monitors

Based on half-life and diffusion length, active as well as passive techniques used for the measurement of radon, thoron, and their decay products are Nuclear Emulsion, Absorption Gamma Spectroscopy, Ionization Chamber, Beta monitoring, Thermoluminescent detectors, Solid-state nuclear track detector. For the measurement of radon, main devices are pinhole dosimeter, alpha-track detectors (ATDs), electrets ion chambers (EICs), and activated charcoal detectors (ACDs). Active devices in use by many countries include electronic integrating devices (EIDs) and continuous radon monitors (CRMs). Passive devices do not require electrical power or a pump to work in the sampling setting, whereas active devices require electricity and include the ability to chart the concentration and fluctuations of radon gas during the measurement period.

Several online radon monitors based on different detection techniques are available for continuous radon measurement. Of these, the following three types of online radon monitors are used most widely. ATDs obtain a long-term radon measurement and are often deployed for a one-year period, while EICs are often used for short (e.g. several days) to intermediate (e.g. weeks to months) measurement periods. EICs also have the ability to integrate the radon concentration over time (e.g. 8-hour home occupancy period), using an open and close feature of the detector. The use of CRMs has become more prevalent as the price of these detectors has slowly declined. CRMs can automatically provide time-resolved information. For active measurement in indoor, mass exaltation and surface exaltation or radon concentration measurement Smart RnDuo, RAD7 are being used in recent research work.
In the first type, the online radon monitor operates as an ionization chamber. Radon in the ambient air diffuses into the chamber through a filtered area so that the radon concentration in the chamber follows the radon concentration in the ambient air with some small-time lag. Within the chamber, alpha particles emitted during the decay of radon atoms produce bursts of ions which are recorded as individual electrical pulses corresponding to each disintegration. These pulses are processed by the monitor electronics; the number of pulses counted is displayed usually on the monitor [31].

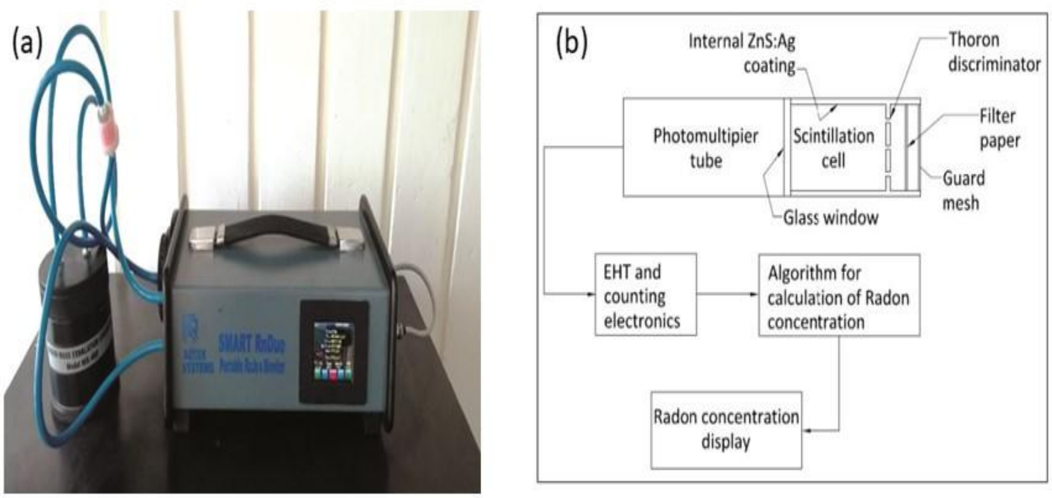

Fig. 3: (a)Smart RnDuo and (b)It's Schematic diagram.

AlphaGuard is the most popular commercially available radon detector of this type. The second type of online radon monitor is based on solid- state silicon detectors, which functions by allowing ambient air to flow through a filter into a detection chamber. As the radon decays, the decay products are collected using an electric field onto a solid- state silicon detector like a PIN diode where the alphas emitted by the decay of these products are detected [32]. Hence, it is possible to spectroscopically distinguish the alphas and thus reduce the error in measurement.

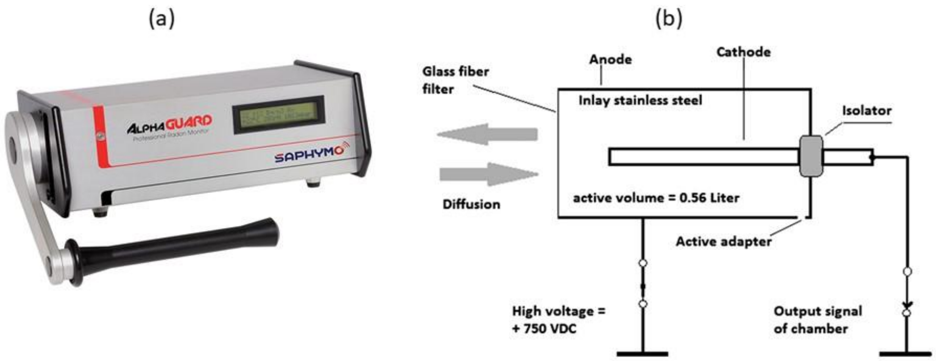

Fig. 4: (a) Alphaguard online radon monitor and (b) It's a schematic diagram.

The RAD7 and RTM- 2200 are popular instruments of this type. However, these detectors are prone to interference due to the presence of humidity and trace gas. In the third type of monitor, ambient air is sampled for radon in a scintillation cell after passing through a filter that removes radon decay products and dust. As the radon in the cell decays, the radon decay products plate out on the interior surface of the scintillation cell [33].The measurements with a scintillation detector are unaffected by humidity and trace gas concentrations present in the sample gas. Alpha particles produced by subsequent decays, or by the initial radon decay, are detected by the scintillation cell and a photomultiplier. This type of online radon monitor uses either a flow- through cell or a periodic- fill cell. In the flow- through cell, the air is drawn continuously through the cell by a small pump. In the periodic- fill cell, the air is drawn into the cell once during each pre- selected time interval; then the scintillations are counted and the cycle is repeated. A third variation operates by radon diffusion through a filter area with the radon concentration in the cell varying with the radon concentration in the ambient air, after a small diffusion time lag [34]. However, this method has a serious problem of background build-up and it is not possible to distinguish background counts from those of radon.

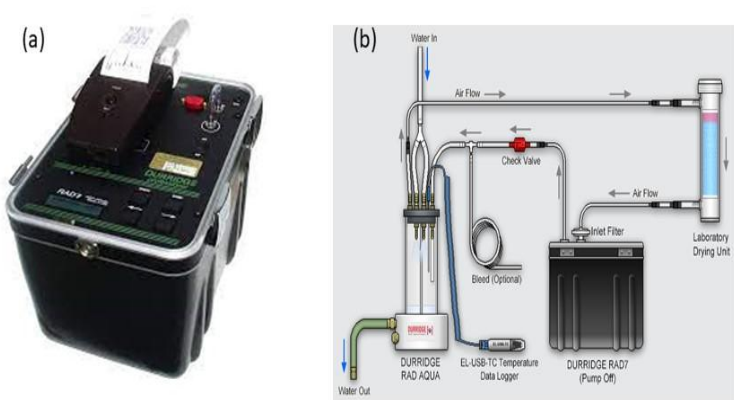

Fig. 5: (a) RAD7 radon detector and (b) its schematic diagram.

Radon accumulates inbound spaces and activity concentration (Bq/m3) augmented over time. Fig. 6 shows the radon activity concentration growth curve in an accumulation chamber attached to an online radon monitor (Smart RnDuo) for one month on an hourly count cycle. Graph demonstrates a plateau region after 300 hours of accumulation in the chamber suggesting the condition of secular equilibrium when all progenies obtained equal activity concentration in the chamber [35].

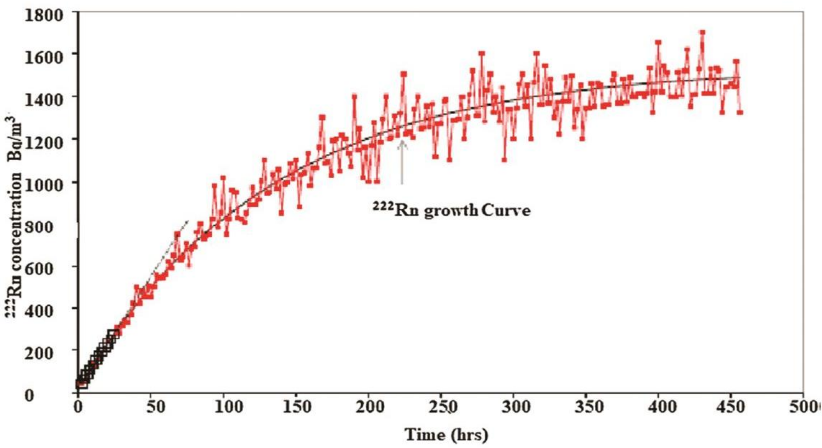

Fig. 6: Radon activity concentration growth curve inside an accumulation chamber using an active radon detector.

Conclusion

Radioactivity is a momental fraction of developments. It's playing a rigorous role from the 19th century so far. As it is useful in medical science yet contains cataclysmal potential as well. Today we can diagnose or can treat dangerous diseases through chemotherapy and radioactive medicine etc. As our dependency is increasing continuously on natural and artificial radioactivity, an upsurge in exposure level also comes with that. With all these impacts historical review of epidemiological studies of underground miners and case-control studies indoor background radiation and other studies performed so far provided convincing evidence of a strong relationship between radon, thoron, and their progeny with lung cancer.

Plenty of researchers investigate ionizing radiation andits associated risk assessment in many countries over the world. But some parts of the world still exist where the knowledge about ionizingradiation or their effects are still sparse. Indian culture is still empty-handed in this area on a domestic level. Various government health organizations and research bodies need to initiate an ionization radiation study program. Some coordinated research programs should include industrialized countries as well as a developing nations. Emphasis should be on areas that will assist in improving the current dose of population groups estimated to receive elevated radiation exposures. Radioactivity measurements on environment and food are commonly performed by testing laboratories for regulatory purposes and public information by using international standards on test methods for radionuclides to minimize the potentially harmful effects of ionizing radiation. Easy detection and mitigation of radon are still to be achieved by humans.

Competing Interests

Authors have declared that no competing interests exist.

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