International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in

Vol.3., S3, 2015

NCERFM-2015

ISSN: 2321-7758

STUDIES ON OCCUPATIONAL DOSE LEVEL OF RADON AND ITS PROGENY –A REVIEW

K. S. HAMSA[*1],C. NINGAPPA[*2], J. SANNAPPA[*3]

[*1]Department of Electronics, Christ University, Bengaluru

[*2]Department of Physics, VidyaVikas Institute of Engineering & Technology, Mysuru
(Affiliated to VTU)

[*3]Departmentof Physics, Kuvempu University, Shankaraghatta, Shimoga

E mail: hamsa.hariharan@christuniversity.in

ABSTRACT

Radon is a radioactive gas which causes significant health hazards in human beings. Radon itself is not a health hazard but the daughter products of radon being isotopes of heavy metals get attached to the existing aerosol particles in atmosphere. Radon is an established human lung carcinogen and stands as the second leading cause of lung cancer death after tobacco smoke. Radon concentration in drinking water increases the risk of stomach cancer and other gastro-intestinal malignancies. This paper gives an insight into occupational dose level of radon and its progenies and discusses about the methods followed for detection, results obtained and health risk associated with radon. A systematic review has been conducted about the recent studies associated with the evaluation of radon gas in dwellings.

Key words: Radon, Thoron, Dwellings, Inhalation dose

1. INTRODUCTION

Radon, a naturally occurring radioactive gas produced by the decay of uranium in soil and rock in the surface of the earth, causes significant health hazards in human beings. All substances found in the terrestrial system contain variable amounts of radioactive nuclides of Uranium (^{238}U, ^{235}U), Thorium (^{232}Th) and their decay products. Uranium has two primary isotopes ^{238}U and ^{235}U, which at present occur in the proportion 99.3 % of ^{238}U and 0.7 % of ^{235}U, respectively. Both the isotopes of Uranium (^{238}U and ^{235}U) exhibit long and complex decay series. Thorium has only one isotope. These undergo radioactive decay until they become stable isotopes. The decay of ^{235}U leads to the formation of ^{219}Rn (also known as actinon) and the decay of ^{232}Th leads to the formation of ^{220}Rn (also known as thoron). ^{219}Rn may be ignored entirely, because ^{235}U is a relatively rare isotope and also because the half-life of ^{219}Rn is only 4 sec. Therefore, almost all the ^{219}Rn will decay before it can escape from the ground.

^{232}Th is abundantly available in the earth's crust, but the short half-life of ^{220}Rn (55 seconds) allows only a fraction of it to escape into the atmosphere. The most significant isotope is ^{222}Rn with a longer half- life of 3.82 days which is formed due to the decay of ^{238}U. Being a gas, radon atoms diffuse from the site of production and ultimately reach the air we breathe. Radium (^{226}Ra), a decay product of ^{238}U, present in soil and building materials is the source of radon in outdoor atmosphere and indoor air. Radon sparingly dissolves in water. Yet considerable radon activity found dissolved in ground water because of the pressure exerted by the soil / rock overburden. When such water is used in houses for domestic purposes radon may get released into the indoor air. Thus radon concentration can reach significant levels in dwellings [1].

Airborne radon itself is not a health hazard but the daughter products of radon being isotopes of heavy metals get attached to the existing aerosol particles in atmosphere, enter the lungs through inhalation, and upon further breakdown emit alpha particles that damage the tissues. Radon is an established human lung

carcinogen and stands as the second leading cause of lung cancer death after tobacco smoke. Radon gas moves freely though soil. When it escapes from the ground into the atmosphere it is diluted and is considered a negligible health risk. When it enters buildings that have confined or poorly ventilated spaces, radon can accumulate to levels considered a health risk[2]. Radon can enter buildings through dirt floors, or cracks and crevices in walls, floors, or around pipes. Heavier than air, radon tends to accumulate in the lower levels of buildings. Recent surveys have confirmed that while radon is ubiquitous in the environment, its concentration levels are not uniform across any large region. Radon concentration in drinking water increases the risk of stomach cancer and other gastro-intestinal malignancies. Exposure to radon in miners induces genetic mutations and chromosomal aberrations. It is also found that the indoor radon concentration is high and far more dangerous than outdoors [2]. Radon revels in indoor air vary depending on geology available entry points into the building, ventilation systems, and whether there is negative air pressure in the building's envelope. Radon levels differ significantly from house to house. As such, it is not possible to rely on test results from neighbourhood averages [1-3].

This paper gives an insight into occupational dose level of radon and its progenies and discusses about the methods followed for detection, results obtained and health risk associated with radon. A systematic review has been conducted about the recent studies associated with the evaluation of radon gas in dwellings.

2. Review of literature

Studies on natural radioactivity and natural environmental radiations are of great importance as they are of interest in health physics, radiation physics and all the allied branches of natural science. The measurement of the concentration of radon and its decay products in indoor air and outdoor atmosphere has been the interest of many research scientists all over the world. The concentration of radon and its daughter products in living spaces depends on the balance between the rate at which they are removed from the air and the rate at which they are introduced. The factors which determine these rates vary significantly from one location and building to another depending on the site and on the details of the building construction.

A great amount of research in the field of radiation hazard conducted since 1942 has been directed towards understanding the mechanisms of radiation injury as well as the ecological relationship that exist in an environment contaminated with radioactive material. Study of radon and its progeny in the environment has always been an important aspect of such studies. Extensive studies have been carried out by various researchers on the concentrations of indoor ^{222}Rn and its progenies in different types of buildings, floorings, walls and ventilation. This section provides information, in some detail, about previous studies associated with the concentrations of ^{222}Rn in outdoor and indoor air.

Marvin Wilkening (1986) [4] made an extensive study on seasonal variations of indoor ^{222}Rn at locations in the south western part of United States and reported high ^{222}Rn concentration during winter and low concentration during summer. He also measured room wise ^{222}Rn concentration and reported high concentration of indoor ^{222}Rn in bed room and kitchen due to poor ventilation. Khan (1988) [5] measured ^{222}Rn and its daughters in indoor environment in Aligarh using Solid State Nuclear Track Detectors (CR-36). The concentrations reported inside rooms ranged from 55.6 to 306.4 Bq.m^{-3}. The dependence of indoor ^{222}Rn concentration on ventilation, sub-soil emanation and the housing materials has been reported. The variation of ^{222}Rn concentration inside the room has been attributed to the usage of internal wall coverings such as plaster, distemper, white washing and use of paints on walls.

Subba Ramu et. al. (1988) [6] made a qualitative study of the seasonal variations in the indoor concentrations of ^{222}Rn and its progeny and reported that both ^{222}Rn and its daughter products are higher during winter and lower during summer. Ramachandran (1990) [7, 8] studied the seasonal variation in concentration of ^{222}Rn and its progeny inside houses in Bombay. Here, the progeny concentrations have been measured using grab sampling method and indoor ^{222}Rn using Solid State Nuclear Track Detector (SSNTD) technique. The average concentration of ^{222}Rn has been reported to be 10.3 Bq.m^{-3} and the average potential alpha energy exposure as 0.79 mWL (grab sampling) and 1.53 mWL (SSNTD). In this measurement, a specific trend in the seasonal variation of the indoor ^{222}Rn concentration has been observed.

Kumar (1991) [9] carried out measurements of ^{222}Rn inside various buildings and mines of Rajasthan using SSNTD technique. The reported values varied from 60 to 122 $Bq.m^{-3}$. The lower values of ^{222}Rn concentration were found in modern houses with good ventilation. Segovia et. al. (1991 [10] measured ^{222}Rn concentrations both in indoor and outdoor using LR115 type-II Solid State Nuclear Track Detector in Mexico city as part of the survey of natural radioactivity in local environment. Low ^{222}Rn concentration of about 40 $Bq.m^{-3}$ was found. The highest ^{222}Rn concentration of 115 Bq. m^{-3} was found inside a house having walls of concrete blocks, dirt floor and no plaster on the walls. Soil ^{222}Rn concentration up to 1500 Bq. m^{-3} was found. No correlation has been observed between atmospheric ^{222}Rn and subsoil structural zone. Shenber (1992) [11] carried out an extensive measurement of ^{222}Rn short-lived decay products and their temporal variation in surface air and observed that the monthly averages ranged from 2.42 to 5.0 $Bq.m^{-3}$ and reported the maximum concentration during winter and minimum during summer. Jatinder Kumar et.al (1994) [12] measured the ^{222}Rn concentrations in dwellings of radioactive areas in Himachal Pradesh using LR-115 Type-II Solid State Nuclear Track Detectors. It is reported that the maximum ^{222}Rn concentration is due to the presence of ^{238}U prospects beneath the soil and the average value of ^{222}Rn concentrations in the villages of Aghar, Chakmoh, Gallot, Khain and Rachaon are found to be 0.73, 0.66, 1.06, 0.88 and 0.71 k $Bq.m^{-3}$ respectively.

Ameer Azam et al., (1995) [13] made an extensive study of monthly variation of indoor ^{222}Rn in Aligarh using LR 115 Type-II Solid State Nuclear Track Detectors and reported that the indoor ^{222}Rn concentration is maximum during winter and minimum during summer. The reported value of effective dose equivalent varies from 0.40 m $Sv.y^{-1}$ to 1.28 m $Sv.y^{-1}$ with a mean value of 0.80 m $Sv.y^{-1}$. Narayan et. al., (1995) [14] have measured the indoor ^{222}Rn concentrations in selected dwellings of coastal Karnataka using LR-115 type strippable films. The ^{222}Rn concentrations varied from 28.4 to 45.6$Bq.m^{-3}$ with a mean value of 35.7 $Bq.m^{-3}$. The estimated annual effective dose equivalent to the people of the region due to inhalation of ^{222}Rn vary from 1.9 to 3.1 $mSv.y^{-1}$ with a mean value of 2.4 $mSv.y^{-1}$.

Ramola (1995) [15] estimated the annual dose from exposure to ^{222}Rn and its daughters in the indoor and outdoor using LR-115 Type-II Solid State Nuclear Track Detectors method in Gharwal area in the Himachal region. The reported values of outdoor ^{222} Rn exposures are 0.078$mWL.y^{-1}$, in indoor mud houses as 0.54$mWL.y^{-1}$ and in cement houses as 0.43$mWL.y^{-1}$. The annual geometric mean value of ^{222}Rn concentrations was 104 $Bq.m^{-3}$ in cement houses and 124 $Bq.m^{-3}$ in mud houses. Fujimoto (1998) [16] observed the direct correlation between indoor ^{222}Rn concentration and dose rate in air from terrestrial gamma radiation in Japan. He reported that the annual concentration vary from 2 to 313 $Bq.m^{-3}$ with a median of 16.0, arithmetic mean of 20.8 and standard deviation of 18.8 $Bq.m^{-3}$. Seluck et. al. (1998) [17] measured the ^{222}Rn concentration in houses and factories in Istanbul, Turkey and reported the measured ^{222}Rn concentrations had a mean value of 47 $Bq.m^{-3}$ and the value of concentration ranged from 17 to 184 $Bq.m^{-3}$ and reported that the ^{222}Rn concentration decreases as the floor number increases. Tesuya Sanada et. al. (1999) [18] carried out the measurement of nationwide indoor ^{222}Rn concentration in Japan and reported that the arithmetic mean, median and geometric mean values for ^{222}Rn concentration were 15.5, 11.7 and 12.7 $Bq.m^{-3}$, respectively. Virk et. al. (1999) [19] carried out an extensive study on indoor ^{222}Rn concentration in Hamirpur and Una districts of Himachal Pradesh. Seasonal variations of ^{222}Rn concentration were reported in this study and observed maximum concentration during winter and minimum during summer and rainy season. The mean value of ^{222}Rn concentration during these seasons is reported to be 81.6 $Bq.m^{-3}$.

Rajesh Kumar et. al. (2001) [20] made an extensive study of the measurement of ^{222}Rn concentration and its daughters in Thermal power station using 115 Type-II Solid State Nuclear Track Detectors method and observed the indoor ^{222}Rn levels to be in the range of 52.2 to 444.8 $Bq.m^{-3}$ with an average ^{222}Rn activity concentration of 228.9 Bq. m^{-3} resulting into the effective dose equivalent of 8.6 mSv. Y^{-1} and reported that the higher ^{222}Rn levels may be attributed due to the power plant area and the utilization of coal enhancing the alpha activity and also due to the poor ventilation.

Saravanan et. al., (2001) [21] measured the ^{222}Rn concentration levels in Madurai, India, using LR-115, Type-II Solid State Nuclear Track Detectors method and reported the minimum value for ^{222}Rn concentration as 5 Bq.m^{-3} and maximum value as 184 Bq. m-3. The average ^{222}Rn concentration in summer is reported to be 38.5 Bq.m^{-3} and that in winter as 69.9 Bq.m^{-3}. The average ^{222}Rn concentration in winter is higher by a factor of 1.8 as compared to that of summer. The yearly average of ^{222}Rn concentration in Madurai is 57.6 Bq.m^{-3} which is comparable with that in autumn (54.6 Bq.m^{-3}). The higher ^{222}Rn concentration is attributed to the type of the building materials used for construction and the temperature variation. Khokhar et. al., (2001) [22] studied the seasonal variation of ^{222}Rn concentration in dwellings of Bilaspur by using LR-115, Type-II Solid State Nuclear Track Detectors method and estimated that the ^{222}Rn concentration in the surveyed houses varied between 49.5 to 7.9 Bq.m^{-3} with the overall arithmetic mean of 23.4 Bq.m^{-3} and the annual effective dose in different types of houses varied from 3 to 10 m. Sv. y^{-1}.

Negi et. al., (2001) [23] made an extensive study of ^{222}Rn concentration levels in Garwal and Kumaun houses of Uttranchal, India and reported that the concentration of ^{222}Rn varied from 11.3 Bq.m^{-3} to 129.7 Bq.m^{-3} in Garwal houses and that from 6.7 Bq.m^{-3} to 63.5 Bq.m^{-3} in Kumaun houses. The reported increase in levels has been attributed to the building materials and types of construction of houses. Surinder Singh et. al., (2001) [24] carried out ^{222}Rn concentration measurements in dwellings of Kulu area, Himachal Pradesh using Solid State Nuclear Track Detectors and the reported values of indoor ^{222}Rn concentration range from 156.1 Bq.m^{-3} to 635.4 Bq.m^{-3}. Deka et. al., (2002) [25] measured indoor ^{222}Rn concentration in different areas of Brahmaputra valley of Assam, India and estimated that indoor ^{222}Rn concentration levels varied from 101.1 to 238.5 Bq.m^{-3}. In the hilly regions of Guwahati and in Namrup, indoor ^{222}Rn concentration levels varied from 132.9 to 197 Bq. m^{-3}. The reported value of inhalation dose for hilly region of Guwahati varied from 0.43 to 1.07 µ. Sv. h^{-1}, while for Namrup, it varied from 0.54 to 0.79 µ. Sv.h^{-1}. The higher ^{222}Rn concentration during winter season has been attributed to the poor ventilation, use of electric devices and coal fires.

Ameer Azam et. al., (2002) [26] measured the monthly variation of ^{222}Rn concentration and its progeny in Aligarh using LR 115 Type-II Solid State Nuclear Track Detectors and reported that the value of indoor ^{222}Rn concentration varies from 28.6 Bq.m^{-3} to 48.6 Bq. m^{-3} with a mean value of 36.2 Bq.m^{-3}. Sreenath Reddy et. al., (2002) [27] carried out extensive study of indoor ^{222}Rn and its progeny concentrations levels in the surroundings of Hyderabad, India, by using LR-115 Type-II Solid State Nuclear Track Detectors and estimated that ^{222}Rn concentration and its progeny levels in different types of dwellings vary from 3 Bq. m^{-3} to 47 Bq.m^{-3} and 0.04 to 3.5 mWL with an average value of 11 ± 8 Bq. m^{-3} and 0.9 ± 0.85 mWL. And the dose due to ^{222}Rn and its progeny is found to vary from 0.01 to 0.20 µSv.h^{-1} . The ^{222}Rn concentration has been reported to be higher in winter and lower in rainy season, the ratio of concentrations from winter to rainy season being 1.6 and similarly the ^{222}Rn concentration has been reported to be higher in winter compared to summer, the ratio of concentrations from winter to summer being 1.3. Also, higher ^{222}Rn and its progeny concentrations have been reported in houses having poor ventilation, mud walls, mud floorings and tiled roofs.

Khalid M. Abumurad et. al., (2002) [28] measured the indoor ^{222}Rn concentration levels in Irbid and health risk from internal doses by using CR-39 detectors. The ^{222}Rn concentrations in Irbid range from 7 Bq. m^{-3} to 230 Bq. m^{-3} with an average value of 44 Bq.m^{-3} and they have reported that the ^{222}Rn concentration decreases as the floor number increases. Andreja Popit et. al., (2002) [29] carried out a systematic study of indoor ^{222}Rn concentrations in relation to geology in Slovenia and reported the relation between indoor ^{222}Rn concentration, rock type, tectonic faults and age of buildings.

Neman et. al., (2002) [30] measured the indoor ^{222}Rn and its daughters concentrations in Campinas Brazil using CR-39 detectors and reported that the ^{222}Rn concentration is influenced by environmental factors and building materials used for the construction of the houses. Higher ^{222}Rn concentrations have been observed in the houses having cement floors. Vinay Kumar et. al., (2002) [31] carried out extensive studies of ^{222}Rn concentration level in Nalgonda district by using LR 115 Type-II Solid State Nuclear Track Detectors and reported that the ^{222} Rn concentration levels vary from 15 Bq.m^{-3} to 461 Bq.m^{-3}.

L.A. Sathish et.al., (2010) [32] and S. Shobha et. al., (2010) [33] reported experimental measurements of ^{222}Rn, ^{220}Rn concentrations and the associated inhalation dose rates due to them in the dwellings of different characteristics in Bangalore. Higher dose rates were observed in lower volume houses and the houses with granite flooring.

Jyoti Sharma et. al., (2012) [34] made a comparative study of indoor radon, thoron with radon exhalation rate in soil samples in some historical places at Jaipur, Rajasthan, India. As the radon progeny contribute a major part of natural radiation dose to general population, attention has been given to the large scale and long term measurement of radon and its progeny. Thoron and its progeny contribute little for the radiation dose in normal back ground region due to its small half life. In this comparative study Solid State Nuclear Track Detectors (SSNTD's) based twin chamber dosimeters were used for estimating radon (^{222}Rn), Thoron (^{220}Rn) gases and Inhalation dose in some historical places at Jaipur, Rajasthan, India using twin chamber dosimeter cups. The dosimeters employ two LR-115 type II plastic track detector peliculable films, cellulose nitrate detector films inside each of the two chambers fitted with filter and polymeric membrane for the discrimination of radon and thoron. Soil samples were also collected simultaneously from different geological formations of the same area for laboratory measurement of radon exhalations rate. Radon concentrations are found to vary from 18.4 ± 3.1 to 62.1 ± 5.7 $Bq.m^{-3}$, whereas thoron concentrations vary from 5.9±0.6$Bq.m^{-3}$ to 22.0 ± 2.6)$Bq.m^{-3}$. Radon activity and radon exhalation rates in the soil samples were also measured by using "Sealed can technique" using LR-115-type II nuclear track detectors. Radon activities are found to vary from 294.2 to 868.4$Bq.m^{-3}$ with an average value of 566 $Bq.m^{-3}$. Radon exhalation rates in these samples vary from 146.8 to 312.2 mBq.m-2h^{-1} with an average value of 203.4 m Bq m-2 h^{-1}.

C. Ningappa, J.Sannappa (2008) [35, 36], (2013) [37] studied the indoor concentration of radon, thoron and their progeny around granite regions of Karnataka, India. Seventy-four dwellings of different types were selected for the measurement. The dosimeters containing SSNTD detectors were fixed 2 m above the floor. After an exposure time of 3 months, films were etched to reveal tracks. From the track density, the concentrations of radon and thoron were evaluated. The value of the indoor concentration of thoron and radon in the study area varies from 16 to 170 $Bq.m^{-3}$and 18 to 300 Bq m^{-3} with medians of 66 and 82.3 Bqm^{-3}, respectively, and that of their progeny varies from 1.8 to 24 mWL with a median of 3.6 mWL and 1.6 to 19.6 mWL, respectively. The equivalent effective dose due to indoor thoron, radon and their progeny in granite regions in Karnataka varies from 0.15 to 9.05 $mSv.y^{-1}$ with a median of 1.31 $mSv.y^{-1}$. The inhalation dose mainly depends on the concentrations of thoron and its progeny. In a few dwellings, concentrations of radon have been observed to be lesser than those of thoron. Higher concentrations of radon, thoron and their progeny were observed in dwellings near the granite region when compared with those in non-granite regions. The concentrations of radon, thoron and their progeny and the equivalent effective dose due to these in the granite regions in Karnataka are higher than the global and Indian averages.

Isa Jasem Al-Khalifa and Hussam Nejam Aood (2014) [38] studied the concentration of indoor radon in some dwellings of Shatt Alarab distract in Basrah Governorate, Iraq, using LR-115 type II solid state nuclear track detectors (SSNTDs). It is reported that the value of concentration of radon ranges from 19.7 to 195.2 $Bq.m^{-3}$ with an average value of 75.1 $Bq.m^{-3}$. The Potential of Alpha Energy concentration (PAEC) in terms of m WL ranges from 2.1 to 21.1 with an average value of 8.1. The annual exposure in terms of WLM ranges from 0.09 to 0.87 with an average value of 0.3. The annual effective dose ranges from 0.34 - 3.37 $mSv.y^{-1}$ with an average value of 1.3 $mSv.y^{-1}$.

The global average indoor and outdoor ^{222}Rn concentrations have been reported as 40 $Bq.m^{-3}$ in indoor and 10 $Bq.m^{-3}$ in outdoor atmosphere on land [39, 40].

3. Measurement Methodology

There are several methods or devices available for detection and measurement of indoor radon and radon decay products [41]. Some of the most commonly used methods for measurement of indoor radon and radon decay products are: Continuous Radon (CR-39) monitors, Alpha track Detectors (AT or ATD) such as

Solid State Nuclear Track Detectors (SSNTD), Activated Charcoal Absorption Devices (AC), Electret Ion Chamber Radon Detectors (EC) etc. These methods are explained in some detail in this section.

3.1 Continuous Radon Monitors

Continuous radon monitors are precision devices that track and record real-time measurements and variations in radon gas concentration on an hourly basis. Air either diffuses or is pumped into a counting chamber. The counting chamber is typically a scintillation cell or ionization chamber. Using a calibration factor, the counts are processed electronically, and radon concentrations for predetermined intervals are stored in memory or directly transmitted to a printer.

A passive radon monitoring device based on CR-39 polycarbonate, alpha trace detectors (ATDs), consists of a small exposure cup that contains the CR-39 chip. Unexposed ATDs are given an etching pretreatment which reduces the subsequent background track density and improves reproducibility. After exposure is complete, the ATD is sequentially etched, chemically and then electrochemically, for easy visualization and counting of etched tracks. At a radon activity concentration of 70 $Bq.m^{-3}$ the accumulation rate is 10 tracks/cm^2-day; an integration time of 28 days produces a signal-to-noise ratio of 10. The background over that time is 30tracks/cm^2. A simple calibration technique is followed. The data are inter compared with a calibrated dynamic detector system.

3.2 Activated Charcoal Adsorption

For this method, an airtight container with activated charcoal is opened in the area to be sampled and radon in the air adsorbs onto the charcoal. The detector, depending on its design, is deployed for 2 to 7 days. At the end of the sampling period, the container is sealed and sent to a laboratory for analysis.

3.3 Alpha Track Detector

Alpha track detectors employ a small piece of special plastic or film inside a small container. Air being tested diffuses through a filtering mechanism into the container. When alpha particles from the decay of radon and its progeny strike the detector, they cause damage tracks. At the end of exposure, the container is sealed and returned to the laboratory for analysis. The plastic or film detector is chemically treated to amplify the damage tracks and then the number of tracks over a predetermined area is counted using a microscope, optical reader, or spark counter. The radon concentration is determined by the number of tracks per unit area. Detectors are usually exposed for 3 to 12 months, although shorter time frames may be used when measuring high radon concentrations.

Solid State Nuclear Track Detectors (SSNTD) are thin plastic dielectric sheets of materials such as cellulose nitrate (CN) and poly carbonates. They are sensitive to alpha but not to beta and gamma radiations. Also, they are unaffected by humidity, low temperatures, moderate heat and light. They are passive detectors and do not require energy to operate as their detecting property is an intrinsic quality of the material they are made of. For indoor measurements, normally the CN films are used as they very specific to alpha radiation detection.

3.4 Electret Ion Chamber

For this method, an electro-statically charged disk (electret) is situated within a small container (ion chamber). During the measurement period, radon diffuses through a filter into the ion chamber, where the ionization produced by the decay of radon and its progeny reduces the charge on the electret. A calibration factor relates the voltage drop, due to the charge reduction, to the radon concentration. Variations in electret design enable the detector to make long term or short term measurements. Short term detectors are deployed for 2 to 7 days, whereas long term detectors may be deployed from 1 to 12 months.

4. Discussion

Radon and its daughter products were measured in a few buildings of different types at some locations in Bangalore city, using SSNTD technique. The results of the measurements are as given in Table-1. The dwellings are classified by the types of construction, roof, floorings and ventilation conditions. From Table-1, it may be observed that, the concentration of ^{222}Rn in indoor atmosphere ranges from 14.27 to 104.0 $Bq.m^{-3}$, with a mean value of 49.52 $Bq.m^{-3}$. The concentration of ^{222}Rn daughter products ranges from 1.54 to 11.24

mWL, with a mean value of 5.29 mWL. The important source of indoor radon is ^{226}Ra, present in soil beneath the ground and in building materials. The building materials used are mostly bricks, cement, granite, tiles etc. The concentration of ^{226}Ra is relatively more in granites [39]. Higher ^{222}Rn concentration and its daughter products have been observed in HSR Layout, as floorings are made up of granites and the dwelling is poorly ventilated.

In Victoria Hospital, the walls are also made up of granites. The flooring of the ground floor room is made up of tiles while that of the first floor room is made up of poly-vinyl materials. The first floor room is air conditioned. In Victoria Hospital, higher concentration of indoor ^{222}Rn and its daughter products is observed in ground floor room. This may be due to the higher concentration of ^{226}Ra present in granites and tiles [43]. The A.C. room shows relatively lower concentration of radon and its daughter products. This may be attributed to A.C. which enhances air exchange rate. The house in Vijaya Nagar shows low concentration of radon and its daughter products. This is because the house is newly constructed and has good ventilation. The concentration of radon and its daughter products in Koramangala is slightly high. This may be due to the reason that the house is quiet old and poorly ventilated, as the windows are always kept closed. The house in Rajaji Nagar has relatively lower concentration of radon and its daughter products which may be because it is on the second floor and has red oxide floorings.

Table-1 gives the inhalation dose to the population in a few dwellings in Bangalore city. To estimate the population dose, conversion factor of 9 nSv, equilibrium factor of 0.4 and occupation factor of 7000 hours is used [39]. The inhalation dose due to radon and its daughter products vary from 0.38 to 2.74 mSv with an average of 1.3 mSv. The houses having granite, tile floorings and walls show higher value of inhalation dose. However, new houses and dwellings with good ventilation show lower inhalation dose value.

Table-2 shows the variation of concentration of radon and its daughter products in different rooms of the same house. The concentration of radon varies from 16.5 to 65.0 Bq.m^{-3} in different rooms of the same house. The concentration of radon daughter products varies from 1.78 to 7.02 mWL. The inhalation dose varies in different rooms of the same house from 0.44 to 1.71 mSv. Higher concentration of radon is observed in bath room and kitchen compared to the other rooms. This may be due to poor ventilation, usage of bore well water which contains high radon concentration [39]. Natural gas also contains high concentration of radon [40]. This may be contributing to the higher concentration of radon in kitchen.

Least concentration of radon and its daughter products observed in hall due to good ventilation (3 windows, 2 doors and 2 fans in hall) and slightly higher concentration observed in bed room (1 window, 1 door and 1fan). Higher concentration observed in store room due to poor ventilation (no window, 1 door and no fan).

Table-3 gives the geometric mean value of the indoor radon concentration levels in different regions of India [7, 8] as well as the world wide concentrations [39, 40] as reported in the literature. These values are summarized in Table 3 for the purpose of comparison. The Indian average value for radon concentration is 25.5 Bq.m^{-3}. The global average of indoor radon concentration is 40.0 Bq.m^{-3}. The mean radon concentration in Bangalore is 49.52Bq. m^{-3} (Table-1), which is much higher than the Indian average value and slightly higher than the global average.

Radon and its progeny concentrations in indoor atmosphere vary with ventilation conditions, types of the buildings and materials used for construction. Higher concentrations of radon and its daughter products are observed in poorly ventilated buildings, houses with granite walls and buildings with granite floorings. Radon and its progeny concentrations in indoor atmosphere vary with different types of floorings. It may be summarized that the concentration of radon and its daughter products are higher in houses with granite flooring. Poor ventilation, usage of bore-well water, natural gas are some of the other factors which contribute to higher radon and its progeny concentration.

5. Conclusion

A systematic review has been made about the recent studies associated with the evaluation of radon gas in dwellings carried out by researchers across the globe. This paper gives an insight into occupational dose

level of radon and its progenies. Also discussed are the methods followed for detection, results obtained and health risk associated with radon. An attempt has been made to measure the concentration of indoor radon and its daughter products in a few houses in Bangalore city. The measurements of indoor radon and its progeny concentrations have been carried out in summer, only in a few houses in limited areas of Bangalore city. The inhalation dose due to radon and its progeny of Bangalore city (1.30 mSv) is observed to be higher than that of the global average value (1.0 mSv). The mean value of concentrations of ^{222}Rn and its progeny measured in Bangalore during summer significantly exceeds the global average. This may be attributed to the presence of granite in and around Bangalore. Hence it is important to carry out further research work during various seasons. More number of measurements in different types of houses to cover larger areas in and around Bangalore city should be carried out. From the point of health risk, this data is not adequate. The present work provides a base line data for further studies related to indoor radon and its progeny concentrations in Bangalore.

Table-1: Concentration of indoor radon (^{222}Rn) and its daughter products in a few dwellings of Bangalore city during the period from 20-02-2005 to 31-05-2005 (summer) [42]

LOCATION	**Concentrations**	**Eq.Eff. (mSv.y^{-1})**	**Dose**
	^{222}Rn (Bq. m^{-3})	**^{222}Rn (mWL)**	**Prog.**
Victoria Hospital Ground Floor (Tile Flooring)	62.52	6.75	1.64
I-Floor (Poly-vinyl Flooring, AC-Room)	38.46	4.15	1.01
Vijaya Nagar (Mosaic Flooring)	14.27	1.54	0.38
HSR Layout (Granite Flooring)	104.00	11.24	2.74
Koramangala (Mosaic Flooring, Old house, Poorly Ventilated)	50.00	5.40	1.31
Rajaji Nagar (Red Oxide Flooring, II- floor)	27.87	2.68	0.74
Mean Value	**49.52**	**5.29**	**1.30**

Table-2: Variation of concentration of indoor radon (^{222}Rn) and its daughter products in different rooms of the same house.

Sl.No	Type of Room	^{222}Rn (Bq. m^{-3})	^{222}Rn prog. (mWL)	Eq. eff. Dose (mSv)
1	Hall	16.5	1.78	0.44
2	Bed room	25.0	2.70	0.66
3	Bath room	65.0	7.02	1.71
4	Kitchen	40.0	4.32	1.05
5	Store room	35.0	3.78	0.92

Table-3: Concentration of indoor radon (^{222}Rn) in different regions.

Indian Scenario		Global Scenario	
Regions	**Conc. of ^{222}Rn (Bq. m^{-3})**	**Country**	**Conc. Of ^{222}Rn (Bq. m^{-3})**
Andhra Pradesh	17.5	China	20.0
Bihar	41.0	France	62.0
Delhi	18.4	Germany	57.0
Karnataka	14.9	India	25.5
Kerala	17.0	Japan	13.0
Rajasthan	21.4	Thailand	16.0
Uttar Pradesh	27.0	U.K.	20.0
West Bengal	13.6	U.S.A	25.0
Indian Average	**25.5**	**Global average**	**40.0**

REFERENCES

[1] BEIR VI, Report of the Committee on the Biological effects of Ionizing Radiation, "Health Effects of Exposure to Low Levels of Ionizing Radiation", Natl. Acad. of Sciences, Natl. Acad. Press, Washington, DC, 1999.

[2] Burgandy Dunn, Kathleen Cooper; Radon in Indoor Air: A Review of Policy and Law in Canada, Canadian Environmental Law Association, November 2014.

[3] A.B. Tanner, "Radon migration in ground: A Supplementary Review", In The natural Radiation Environment III, T.F. Gendsell and W.M. Lowder (Eds), University of Chicago press, 1980, pp. 5-56.

[4] Marvin Wilkening, "Seasonal Variation of Indoor 222Rn at a location in the South Western United States", Health Physics, Vol.51, pp. 427-437, 1986.

[5] Khan A.J., Sharma K.C., Varshney A.K., Rajendra Prasad and Tyagi R.K., "Measurement of Concentrations of Radon and its daughters in indoor atmosphere using CR-39, Nuclear Track Detector, Indian J. Pure and Applied Phys., 26, 425-427, 1988.

[6] Ramachandran T.V., Muraleedharan T.S., Shaikh A.N. and SubbaRamu M.C., "Seasonal Variation of Indoor 222Rn and its progeny concentration in dwellings", Atmospheric Environment, Vol. 24A, pp. 639-643, 1990.

[7] SubbaRamu M.C., Muraleedharan T.S., Ramachandran T.V. and Shaikh A.N., "Methods and Measurements of Indoor Levels of 222Rn and its Daughters" BARC Rep. No. 1390, 1988.

[8] Ramachandran T.V., and Subba Ramu M.C., "Control Methods of ^{222}Rn and the Progeny Concentrations in Indoor Atmosphere", BARC Rep. No. 1498, 1990.

[9] Kumar. S., Deepak Gopalani, Rao M.V.N., Ramaseshu P., and Nagarathnam A., "Estimation of ^{222}Rn Levels in Environment", Indian Journal of Environmental Protection, Vol.11, pp.375-377, 1991.

[10] Segovia N., Pena P., and Tamez E., "^{222}Rn Survey in Mexico City", Nucl. Tracks Radiations and Measurements, Vol. 19, pp. 405-408, 1991.

[11] Shenber. M.A., "^{222}Rnand Short Lived Decay Products and their Temporal Variation in Surface air in Tripolli ", The Science of the Total Environment, Vol. 119, 243-251, 1992.

[12] Ameer Azam, Naqui A.H., and Srivastava D.S., "Measurement of monthly Variation of ^{222}Rn and its progeny using LR-115 Type-II Track Detectors", Proc. 21st Int. Symp on Nuclear Tracks in Solids, 1995.

[13] Narayana Y. Indoor ^{222}Rn Levels in Coastal Karnataka", Proc. 4th National Symp. On Environment, Madras, 190-193, 1995.

[14] Ramola R.C., Rawat R.B.C., and Kandri, M.S., "Preliminary Measurement of ^{222}Rn Concentration in Mud houses using LR-115 Plastic Track Detectors", Proc. 4th National Symp. on Environment, 199-200, 1995.

[15] Fujimoto, "Correlation between Indoor ^{222}Rn concentration and dose rate in air from Terrestrial Gamma Radiation in Japan", Vol. 75, pp. 291-296, 1998.

[16] Selcuk A.B., Yavuz H., Koksal E.M., and Ozcinart B., ^{222}Rn Concentration in Elazing houses and factories", Radiation Protection Dosimetry, 77, 211-212, 1998.

[17] Tesuya Sanada, Kenzo Fujimoto, KeijiMiyano, Masahiro Doi, Shinji Tokonami, Masaki Uesugi, Yoshinori Takata, " Measurement of Nationwide Indoor ^{222}Rn Concentration in Japan", Journal of Envir. Radiation, 45, 129-137, 1999.

[18] Virk. H.S., Navjeet Sharma, B.S.Bajwa, "Environmental Radioactivity: A Case Study in Himachal Pradesh, India", J. of Envir. Rad. 45, 119-128, 1999.

[19] Rajesh Kumar, Rajeev Kumar, Ashwini Kumar and Rajendra Prasad, "Measurement of ^{222}Rn and its daughters in Thermal Power Station using Solid State Nuclear Track Detectors" , Proc. 12Th Nat. Symp. on SSNTD, Jalandhar, India, 158-160, 2001.

[20] Saravanan., Estimation of ^{222}Rn Levels in Madurai using SSNTD", Proc. 12Th N. Symp. on SSNTD, Jalandhar, India, pp. 138-141, 2001.

[21] Khokhar M.S.K., Kher R.S., Rathore V.B., and Ramachandran T.V., "Seasonal Variation of ^{222}Rn and ^{220}Rn Concentrations in Dwellings of Bilaspur, CG and nearby Regions, India", PProc. 12Th N. Symp. on SSNTD, Jalandhar, 127-133, 2001.

[22] Negi M.S., Bisht R.K., Kandari M.S., and Ramola R.C., "Comparative Study of ^{222}Rn / ^{220}Rn Levels in Garwal and Kumaun Homes of Uttaranchal", Proc. 12Th N. Symp. on SSNTD, Jalandhar, India, 155-157, 2001.

[23] Surinder Singh, Rajeev Malhotra, Jatinder Kumar and Lakhwant Singh, "Indoor ^{222}Rn measurements in Dwellings of Kulu area, Himachal Pradesh, Using Soild State Nuclear Track Detectors", Radiation Meas., 34, 505-508, 2001.

[24] Deka P.C., Subir Sarkar, Sarma B.K and Goswami T.D., " Indoor ^{222}Rn / ^{220}Rn Levels in Different areas of Brahmaputra valley of Assam, India", Proc. 21st Int. N. Conf. on Nuclear Tracks in Solids, New Delhi, 2002.

[25] AmeerAzam, Naqui. A.H., and Srivastava. D.S., "Measurement of Monthly Variation of ^{222}Rn and its progeny using LR-115 Type-II Track Detector", Proc. 21st Int. N. Conf. on Nuclear Tracks in Solids, New Delhi, 2002.

[26] Sreenath Reddy, Sreenivasa Reddy, Gopal Reddy, Yadagiri Reddy and Ram Reddy, "Study of indoor ^{222}Rn and its Progeny Concentrations Levels in the Surroundings of Hyderabad, India", Proc. 21st Int. N. Conf. on Nuclear Tracks in Solids, New Delhi, 2002.

[27] Khalid M. Abumurad et. al., "Indoor ^{222}Rn Levels in Irbid and Health Risks from Internal Doses", Proc. 21st Int. N. Conf. on Nuclear Tracks in Solids, New Delhi, 2002.

[28] Andreja Popit, JaniaVaupotic, "Indoor ^{222}Rn Concentrations in Relation to Geology in Slovenia", Environ. Geology, 42, 330-337, 2002.

[29] Neman R.S., Hadler J.C., Iunes P.J., Paulo S.R., Guedes S.O., Tello S.C.A., and Souza W.F., "Indoor ^{222}Rn and ^{222}Rn Daughters RD Survey at Campinas, Brazil Using CR-39 Final Results", Proc. of 21st Intl. Conf. on Nuclear Tracks in Solids, New Delhi, 2002.

[30] Vinay Kumar Reddy K., Srinivasa Reddy B., Sreenath Reddy M., Ch. Gopal Reddy , Yadagirireddy P., and Rama Reddy K., "Study of indoor ^{222}Rn and its Progeny Concentrations Levels in Nalgonda District, Andhar Pradesh ", Proc. of 21st Int. Nat. Conf. on Nuclear Tracks in Solids, New Delhi, 2002.

[31] L. A. Sathish, H. C. Ramanna, V. Nagesh, K. Nagaraja, S. Shobha, S. Sundareshan and T.V. Ramachandran, "Effective radiation dose due to indoor radon and thoron concentrations in Bangalore city, India," The Arabian J. for Science and Engineering, 35, 202, 2A, 201-208, 2010.

[32] S. Shobha, L.A. Sathish, S. Sundareshan and T.V. Ramachandran, "Inhalation Dose Due to Indoor Radon" , Int. Nat. J. of Pure and Applied Physics, 6, 3, 257–262, 2010.

[33] Jyoti Sharma, A. K. Mahur, Rupesh Kumar, RatiVarshney, R. G. Sonkawade, R. Swarup, Hargyan Singh and Rajendra Prasad, "Comparative study of indoor radon, thoron with radon exhalation rate in soil samples in some historical places at Jaipur, Rajasthan, India", Advances in Applied Science Research, 3 (2): 1085-1091, 2012.

[34] C. Ningappa, J. Sannappa, M. S. Chandrashekara, and L. Paramesh, "Concentrations of radon and its daughter products in and around Bangalore city," Radiation Protection Dosimetry, 130, 4, 459–465, 2008.

[35] C. Ningappa,., Sannappa, J. and Karunakara, N. Study on radionuclides in granite quarries of Bangalore rural district, Karnataka, India. Radiation Protection Dosimetry, 131, 4, 495–502, 2008.

[36] J. Sannappa and C. Ningappa, "Indoor concentration of Radon, Thoron and their Progeny around granite regions in the State of Karnataka, India" Radiation Protection Dosimetry, 158, 4, 406–411, 2014.

[37] Isa Jasem Al-Khalifa and Hussam Nejam Aood, "Indoor Radon Levels and the associated effective Dose Rate Determination at the Shatt-Alarab Distract in the Basrah Governorate, Iraq, International Journal of Research in Applied, Natural and Social Sciences 2321-8851; ISSN(P): 2347-4580, 2, 3, 117-122, 2014.

[38] UNSCEAR (2000), "Sources and Effects of Ionizing Radiation", Report to the General Assembly-UN, New York, 2000.

[39] UNSCEAR (1993), "Sources and Effects of Ionizing Radiation", Report to the General Assembly with Scientific Annexes, 1993.

[40] USEPA (1992), "Indoor Radon and Radon Decay Products Measurement Devices Protocols" United States Environmental Protection Agency, 1992 www.epa.gov/radon/pubs/device_protocols.html

[41] K. S. Hamsa, "Preliminary study on indoor radon and its daughter products in few buildings of Bangalore city", M.Phil Thesis / Dissertation, Bharathidasan University, India, 2005.

[42] UNSCEAR, Report -82, 37th Session, Suppl. No., 45 (A/37/45) UN, NY, 1982.

[43] Jatinder Kumar, Rajeev Malhotra, Jaspal Singh and Surinder Singh, "^{222}Rn Measurements in Dwellings in Radioactive Areas in Himachal Pradesh, India using LR-115 Plastic Track Detectors", Nucl. Geophys., Vol. 6, pp. 573-576, 1994.