Radon is a gas with symbol Rn and atomic number 86. It’s an active, colorless, odorless, tasteless gas formed from decaying of uranium. It is one of the densest gas, and also a health hazard due to its radioactivity. Uranium is the parent compound from which radon is formed. Uranium has been there since the earth was formed. Thus it will be present for millions of years in the same concentration as now. Uranium is present in various rocks, soil and water. The natural sources of Uranium are granite, phosphate, shale and pitchblende. Uranium 238, decays into Thorium 230, which further decays into Radium 226 and finally into Radon 222. Radon further decays into lead. Radon has 3 isotopes, Radon 222, Actinon and Thoron. Thoron and Actinon have relatively shorter half lives in seconds and hence have limited radioactivity hazards. Radon 222 is the most stable with half life of 3.8 days. (EPA, 2013)

History

Radon was first discovered in 1900’s. The effects of radon comes from the studies that investigated the exposure on miners. In early 1900’s, many miners died early because of lung disease and researcher concluded that the causes were dust and gases in mines to which they were exposed for years. However epidemiological studies with longer study duration in underground miners uncovered the real cause to be radon exposure. A systematic review of 12 epidemiological studies including 60,000 miners in 8 different countries between 1941 to 1990, found the association and causality between 2600 lung cancers and radon exposure. Further, 2 large studies conducted in China and Sweden also found higher rates of lung cancers in miners exposed to radon. According to EPA, radon is the second largest cause of lung cancer. Radon exposure are not limited to lung cancer but can also cause a number of respiratory issues like emphysema, fibrosis, or pneumonia. In addition, radon exposure can also cause reduction in lung volumes and function. (Alavanja CRM, 1994)

Toxicology and risk assessment

The primary route of exposure of radon and its decay particles are through inhalation. Charged ions can easily bind to surfaces like floors, walls and clothing. Further, these ions can be inhaled by humans and animals and can attach to the respiratory epithelium. Most of the radon inhaled will be exhaled. However, 90 % of the absorbed radon is exhaled. Remaining 10 % decay into alpha particles and cause radioactive effects on lung parenchyma and cause cancer. According to the United States Environmental Protection Agency (EPA), radon is the second most frequent cause of lung cancer, after cigarette smoking and combined they have a synergistic action. (EPA 2013)

Radon gas at levels of 4 picocuries per liter (pCi/L) or greater, pose the greatest risk. In studies which involved miners, workers exposed to radon levels of 50- 150 picocuries per liter of air for about 10 years have been associated with increased risk of lung cancer. Radon concentration in air is expressed as picocuries per liter in the US. However, in Europe, it is expressed as becquerels per cubic meter (Bq/m3). Bq and pCi measure nuclear disintegration of radon into its daughter ions. 1 pCi equals to 37 Bq/m3. Radon progeny concentrations are expressed as working levels (WL). One WL is defined as the level of radon progenies in liter or
air that results in release of $1.3 \times 10^5$ million electron volts of alpha energy. A level of 0.02 WL equal to 4pCi/L in a typical home. (Harley, 1988)

Not everyone exposed to radon will develop lung cancer. It depends on the duration and the level of exposure. Further as mentioned early it also depends on the history of smoking along with radon exposure from air, water could also be a source of radon exposure. Ground water poses more risk than surface water. Ingestion of water causes stomach cancer due to the radioactive decay and cause harm to stomach lining. Relationship between exposure to radon and developing lung cancer is linear and the slope increases if smoking is associated with the same. In other words, doubling the exposure will increase the risk of lung cancer by 2 times and halving the exposure will decrease it by 50%. Majority of radon exposure comes from air which is approximately 95%. However, less than 5% comes from water. Most of the water exposure comes from drinking contaminated water, bathing and wearing clothes that have been washed using radon contaminated water. The US EPA has charts to assess the risk of radon exposure for individuals and additionally for smokers and nonsmokers. (Lubin, J.M. and Weinberg, C. 1990)

Not everyone exposed to elevated levels of radon will develop lung cancer. It is dependent on the level and duration of exposure. Research also suggests that drinking water with high level of exposure could cause stomach cancer though association has been low. The National Academy of science has published a report on radon exposure from drinking water. The paper which is titled “Risk Assessment of Radon in Drinking Water” released in 1999 concluded that radon exposure in drinking water will cause approximately 19 stomach cancers deaths per year. (Neuberger JS, 1991)

Health effects of long term exposure to radon has been studied both in animals and in humans. Further extensive research has been done in miners from which results have been extrapolated. However, no deaths have been reported from acute exposure to high levels of radon. Most of the studies have looked at long term exposure to radon out of which majority being observational studies in miners with follow ups in decades. In early 1900’s, miners presented with respiratory problems like emphysema, chronic bronchitis and also lung cancer. Initially the cause for the decreased respiratory status of miners were reported to be due to dust and gas. However later studies done in animals showed the correlation between radon exposure and lung disease. The above was extrapolated with humans. However it is unclear whether very low dose exposure to radon will result in long term respiratory diseases. The mechanism for decreased respiratory function is due to the decay of radon into alpha particles and further damage to respiratory epithelium. (Puskin JS, Nelson CB, 1989)

The risk of lung cancer from radon exposure in homes could be extrapolated from the studies done in miners since the exposure in homes are very low. There are many uncertainties to the studies done in home exposure due to low exposures. Further the bias comes from smoking exposure and other radiation exposures. The risk of developing lung cancer with life time exposure to radon of 20 Bq/m3 at home is estimated to be 0.3% or 3 deaths per 1000 people. However, the risk of accidental death at home the prevalence of which is also very low is estimated to be 0.7%. From the comparison above, we could assess that since the prevalence of the same is so low, studies have used miners as historical controls to obtain the data on lung diseases due to radon exposure. The type of lung cancers caused by radon exposure are – squamous cell cancer, small cell and adenocarcinoma and large cell ca. So radon exposure can cause all types of lung cancer. (Puskin JS, Nelson CB, 1989)

Apart from lung disease, radon exposure can also affect a number of other body systems like hematological, gastrointestinal, neurological systems. Alteration in hematological cells from
radon exposure has been studied only in animals. To date, no human studies have demonstrated any hematological effects from radon exposure. However animal studies have shown decrease in red blood and white blood cells due to the bone marrow suppression. Childhood leukemia has also been linked to radon exposure though recent studies have not found a clear linkage between the two. It has been seen by both acute exposure to high levels and also long term exposures to low levels in animals. (Henshaw DL and Richardson RB, 1990)

Similarly, neurological effects have also been studied only in animals. It is speculated to cause respiratory paralysis by central nervous system depression. Radon exposure is also known to cause renal diseases like nephritis and chronic kidney disease after decades of exposure. Reproductive system is another system that has been studied. Chromosomal aberration particularly X chromosome is more vulnerable to radon effects when compared to Y as Y seems to be more resistant to radiation. The above data comes from observational studies in miners. Further chromosomal aberrations has also been observed in humans with residential exposure to radon. Teratogenic effects of radon exposure has not been demonstrated to date. The US EPA estimates that approximately 20,000 American’s die of lung cancer every year due to radon exposure. (Henshaw DL and Richardson RB, 1990)

Impact
The average national indoor radon level in all 50 states is approximately estimated to be 1.3 pCi/L. The average indoor radon levels of Cuyahoga County is estimated to be 2.7 pCi/L. In Ohio, it is estimated that 62.5% of schools have a potential for at least one room in excess of the US EPA action level (4 pCi/l) compared to 19.3% nationwide. Indoor radon hazards normally varies with the time of the day, humidification, and also season of the year.

Populations that are more susceptible to radon exposure are people with underlying lung diseases like emphysema, chronic bronchitis, asthma, fibrosis. Though children have also been suggested to be vulnerable population for radon exposure, limited data exists for the same. However some researchers have suggested that the amount and duration of radon exposure needed to cause lung cancer in children could be low compared to adults. (EPA 2013)

Radon in homes
As mentioned earlier, radon is formed from radioactive decay of uranium and its daughter ions in rocks and soil. Once radon is produced it is released into air or water. The soil or rocks contain pores from which the radon is released. Radon is then transported through mechanical flow of water and air. Radon enters the houses from cracks through the concrete floors and walls. Further, it also seeps into the pipes and drains and mixes with water. Hence, radon is mostly found at the basement and ground level. Additionally, radon concentrations varies with time of the day, season and hence accurate measurement is difficult. Hence measurements are done for months to get an accurate estimation. Ground water is a potential source of radon than surface water. The reason being suggested is the volatile nature of radon. Rural household wells are potential sources of radon due to the uranium content of the underlying rock and the ground flow patterns. Additionally, water from wells normally have higher concentrations of radon than surface water sources like lake and streams. The US National academy of Sciences has estimated the level of radon to be around 20 Bq/L in ground water compared to 0.4 Bq/L in surface water. One of the attributing factors for stomach cancer has been drinking water contaminated with radon however the association has been weak. Since the incidence of stomach cancer is much
lower than lung cancer due to the radon exposure, most importance is given to mitigating air exposure. (Hendee WR and Doege TC, 1987)

As mentioned above most radon in homes and building come from the soil and ground beneath it. Since the air pressure is lower in the indoors when compared to rocks and soil the radon seeps into the lower pressure areas. Further, trace amounts of uranium can also be found in the rocks used to construct the building, however these seldom seems to be the major source. The radon usually escapes from the cracks in the floor, joints in construction materials and gaps around the pipes and drains. Also, radon which is dissolved in water, tends to escape into the surrounding air. Outdoor air could be another source of indoor radon. The outdoor radon concentrations could change but is usually around 0.4 pCi/l. Radon though present in all 50 states, the concentration could vary drastically from state to state. Also new homes are not different to old homes in terms of radon levels. (Cohen BL, 1991)

Solutions

Radon is a well known carcinogen. EPA has recommended an inexpensive low cost test kits to detect the levels of radon. It is important to know that the threat is completely preventable. As mentioned previously the level of radon indoors depends on the concentration of radon in the soil gas under the house, the construction material used for the house, the planning, ventilation and air conditioning system.

The types of radon detectors used include etched track or alpha track, electret ion chamber, charcoal detectors. It is possible to see drastic differences in radon levels with neighboring houses due changes in construction, design and ventilation. The only way to reliably measure radon in homes is to use passive detectors that are mentioned earlier. Because radon levels varies from time to time, from day to day and also seasons, it is ideal to measure it over a period of time. To accurately detect radon exposure, detectors should be used in rooms were people spend most of the time like bedrooms, living rooms. Charcoal detectors are used for only few days to weeks and hence give less accurate measurements of radon exposure. Electret ion chambers could be used for both short term and long term radon exposure measurement. Similarly, Etched track could also be used to detect radon exposure from one to 12 months period. These detectors could be rented or bought from companies but should be returned for assessment. EPA and the surgeon general recommend testing all homes below the third floor including the basement. With charcoal detectors, an airtight container containing the activated charcoal is exposed to the area. The charcoal is exposed to a variable period of time and hence absorbs the surrounding radon and further is used to detect the levels. In alpha tract detection, the sealed container contains a film which is exposed to the air. The alpha radiation from radon decay hits the film and cause damage tracks which is read using an optical reader. The number of tracks per area is used to detect the level of radon exposure. There are 2 methods of detecting radon exposure. One is short term duration between 2 – 90 days and other is long term more than 90 days. Since radon levels change from time to time it is better to check long term to have a reliable estimate of the same. And would help in designing mitigating efforts. The short term testing is initially used a as a screening period. The EPA recommends to test for radon levels in cold months for a period of greater than 3 months or greater to get a reliable estimate of radon levels. (Henschel DB, 1988)

Testing should be done during the weekdays and also in closed conditions so that it simulates the conditions to accurately measure radon exposure. Although short term ventilation with open windows may not jeopardize the results, it is ideal to actually try to get the
measurements in closed condition as much as possible especially when testing for shorter
duration. Further the testing should be done in colder months so that the heating system is on and
windows are closed and ventilation is minimal. These measures taken would give a better radon
level estimation as the error would be minimal. If the short term testing shows an elevated level
of radon, it should be confirmed by a repeat. Either a repeat short term or long term could be
used. Radon level measurement should be done by trained personnel. If the short term level is
below the hazardous level of 4 pCi/L, periodic repeat measurements should be done. Also if
there is evidence of detector tampering, the test should be repeated. Sometimes trained personnel
use 2 detectors to increase accuracy of the test results. If 2 instruments are used in the same
room, average of the two readings are taken into consideration. (U.S. Environmental Protection
Agency, 1986)

Reducing radon exposure

Radon may be reduced at home by a number of ways. The five principle ways of
reducing radon levels are

1) Improving indoor ventilation
2) Increasing ventilation beneath the floor
3) Sealing cracks in floors and walls
4) Installing a radon sump system
5) Installing a ventilation system.

The above can be achieved by

1) Active Sub-slab Depressurization: is formed by a series of underground pipes that
penetrate the slab and create a negative pressure and prevent the radon from entering the house.
It is very effective in preventing the radon entry into house but is futile when already the indoor
radon levels are high to begin with.

2) Heating, Ventilation and Air Conditioning (HVAC) system:
HVAC system may help reduce the levels of already existing increased radon level. The
ventilation system with underlying pressure may create a negative or positive pressure
ventilation to increase the flow of air within the house. Pressurization may include additional
heating, cooling, and dehumidification to reduce the levels of radon in house.

Further an extract pipe can be installed beneath the floor connected to the floor to release
the radon directly to outside above the roof into air. Gaps between the floor and cracks of house
can be sealed. The previous solutions for reducing radon levels in doors were for old houses.
Recently the focus has changed on preventing the radon levels by concentrating on new houses.
Newly constructed houses have been using inexpensive radon resistant materials to build the
house. Further the ventilation and air-conditioning is designed to mitigate the radon exposure.
Also the air-conditioner is not overloaded and hence dehumidification of indoor air is constantly
obtained. The average cost of installing a radon mitigation system in a new home is around 1200
$. (U.S. Environmental Protection Agency, 1986).

New homes constructed in areas of the state known to have high levels of radon should
include at least:
1) A depressurization system under the floors
2) Layer of gas permeable material under the foundation (usually four inches of gravel),
3) Sealing of all openings in the walls and floors
4) Ventilation for exhaust and combustion appliances.
5) Installation of a pipe that runs from under the floor to the roof. (Henschel BD, 1993, EPA 2013)

Water supply could also be a source of radon exposure. The radon risk from water comes from ingestion of contaminated water and also inhalation as majority of radon in water escapes to surrounding air. Research has further shown that risk of stomach cancer is very low compared to lung cancer and hence humans are more likely to die from inhalation than water ingestion. Radon exposure is minimal when the source of water supply is surface water. However, when the source of water is a private well or a public water supply system, radon exposure could reach levels that could cause harm. Some public water systems treat the water before it is delivered to home. There are two ways, radon exposure from water can be mitigated- One is at the point of entry and the other is at the point of use. Point-of-entry treatment is more effective means of radon removal than point of use. These measures include using either granular activated charcoal (GAC) filters or aeration system. The GAC filter system is cheaper but requires periodic change of filters and also adequate disposal after use. The aeration system is expensive but could be used for longer duration and does not need periodic change. Point-of-use devices are not effective in reducing the risk from breathing radon released into the air from all water used in the home. (U.S. Environmental Protection Agency, 1987).

**Future scope/ measures**

A number of strategies could be used to improve the methods for radon detection and also towards early detection and mitigation to avoid long term health effects.

Though the EPA has published the data on radon levels in all 50 states, further research would be needed in dividing each states into zones to predict the levels of radon exposure from low to high. By dividing each states into zones, we could concentrate measures to mitigate the effects of radon exposure in humans living in zones with highest radon exposure.

Secondly, creating people awareness about the harmful effects of radon exposure could reduce the burden on the government itself when people will take initiatives to reduce their radon exposure indoors and also from water.

Thirdly, increasing awareness about radon testing kits among people would help people to test their house for radon levels.

Fourthly, utilizing home radon testing as a part of community education to increase awareness about the same.

Fifthly, educating the new home buyers about radon will make them aware whether the house that they are buying has been tested appropriately for radon levels and also whether the construction has followed the norms to prevent radon exposure.

Sixthly, real estate agents should be encouraged to hand a radon tested papers to new home buyers and also instruction on future periodic testing.

Seventhly, the government should give tax exemption to home owners for radon testing periodically which may act as an incentive to them to do periodic radon testing.

Eighth, community events about radon testing would enlighten the people staying in a community about the same and also spread the education among non members. Further, rewards for home owners for least indoor radon levels will encourage all to improve their efforts for the same.

Ninth, further research on better techniques of radon detection when compared to present.
Finally, better techniques to mitigate radon levels both indoors and in water.

In conclusion, though we have come far ahead in our efforts of radon detection and mitigation, we are still miles away from our goal.

References:


