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RADON – A SILENT THREAT CATALYSING A FUTURE PUBLIC HEALTH CRISIS

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Abstract: Radon is an element that is dissolved and can sometimes be found in water wells. One cannot smell, see, or taste radon. However, one can drink it, especially when the main water source is the water well. Having radon in water is one of the common problems of modern homes nowadays. This element can bring health problems in the long run. This article aims to discuss what radon is and its sources and its spatial spread. Also, this will tackle the health risks of radon in the water. Lastly, this will give examples of how to remove or reduce radon in the water source successfully.

- **Introduction**: Radon is a ubiquitous gas naturally found in the environment that is radioactive in nature. It was first discovered by a German chemist named Friedrich Ernst Dorn in 1990. Radon is produced through the decay of radium. It is colourless, radioactive, and odourless if it is at room temperature. Since radon is a gas, one can easily inhale it, and the tissues of the body are easily exposed to radiation. Indeed, it has a short half-life. However, it can decay into longer, solid, and radioactive elements, collecting dust particles and being inhaled. Meanwhile, if it is in its solid-state, it is yellow and becomes orange-red when it's at low temperature. Small amounts of radon are used by modern hospitals to aid in treating cancer and other related therapies. The prescribing doctor must weigh up the benefits (pain alleviation) and the risk (cancer risk) for patients when prescribing radon therapies. Other usages of radon include:

- Radon healing adits, in which patients are exposed for a few hours to an atmosphere with a high radon concentration (around ten treatments of around one hour duration per treatment) and absorb radon trough the skin and trough the lung by breathing.
- Radon baths, in which patients bathe in radon-rich water and absorb radon mainly through the skin.
- Radon air baths respectively radon steam baths, where patients sit in a covered tub in radon gas respectively radon steam and absorb radon through the skin.
- Radon waters, where patients drink spring water with high radon concentrations and absorb radon through the gastro-intestinal system.

The benefits and risks of radon therapy are controversial: Radon concentrations in radon healing caves are extremely high. Since the patients are exposed to this radon concentration only for a short time, however, their risk of developing lung cancer increases only slightly as a result of the treatment. But even this increase in risk is only justified if a corresponding medical benefit is to be expected. If radon is absorbed mainly through the skin and/or through the gastro-intestinal system during bathing or drinking, the radiation-related risk of contracting lung cancer is significantly lower than in radon galleries because only small quantities of radon reaction products are inhaled. It has been found that employees at workplaces in radon spas and radon healing adits have very high exposure levels.

Sources of Radon:

Radon can be formed from radium decay, which can be found in rock, soil, and water. If it is from the soil, then it is coming from the crust of the Earth. It escapes through the crevices and cracks in the bedrocks. It might also come from the foundation cracks or basements of your homes which are poorly sealed.

Also, it might come from the radium that is dissolved in the groundwater and becomes the source of your water supply. The radon can be trapped in homes and become dangerous in the long run. The concentration is much greater in underground basements and cellars in homes. Radon found in water is usually from the water wells and drilled in the bedrock with radon gas. The wells can be either private water wells or wells with a public water supply system. However, radon does not usually occur in high concentrations in surface water.

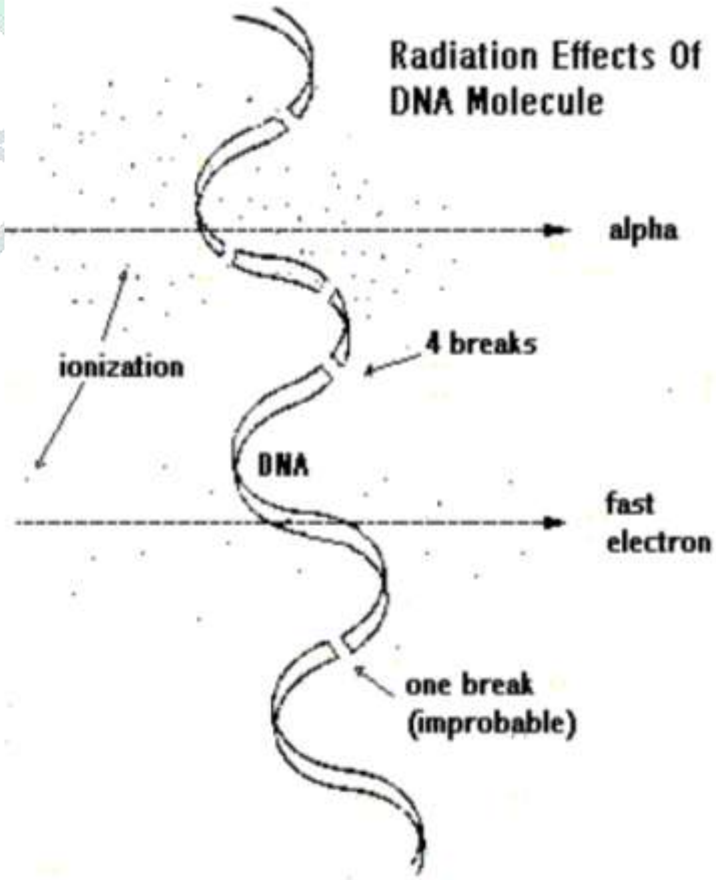
Now, the dissolved radon can escape into the air when one opens the water, and takes bath, do laundry, wash dirty dishes, and cleans rooms. According to studies, the estimated indoor air radon concentrations can increase by about one pCi per liter for every 10,000 pCiliters of water. For example, if the water well contains 2,000 pCi per liter of radon, one can expect to have 0.2 pCi per liter of radon to the indoor concentration. EPA says that indoor air should not have more than four pCi of radon per liter to prevent the potential for cancer. The different states in America, plus the EPA, recommend that the standard drinking water must have 300 to 10,000 pCi per liter of radon only, but no standard currently exists.

Health Effects of Radon

The cause of lung cancer is generally attributed to tobacco smoking. However lung cancer in never smokers accounts for 10 to 25% of all lung cancer cases. Radon is a prominent non-tobacco carcinogen strongly associated with lung cancer. Exposure to such agents can lead to genetic and epigenetic alterations in tumor genomes, impacting genes and pathways involved in lung cancer development. Moreover, radon not only exhibit unique mechanisms in causing genomic alterations, but also exert deleterious effects through common mechanisms, such as oxidative stress, commonly associated with carcinogenesis. Studies show that inhaling radon can increase one’s chance of having lung cancer greater than stomach cancer. When someone breathes in radon gas, it goes into their lungs, exposing them to small amounts of radiation. This may damage the cells in the lining of the lungs and increase a person's risk of lung cancer. The risk is higher in those who have lived for many years in a radon-contaminated house. One can also likely increase his chance of getting lung cancer if he is exposed to radon, plus he is a chain smoker.

What happens when radon and radon progeny are inhaled or ingested? Because radon is chemically inert, radon that is inhaled is also exhaled. Radon progeny, however, are chemically active, being metals, such as lead, bismuth, and polonium. These elements will stick to anything with which they come into contact such as particulates in the air, furniture and room surfaces.

When inhaled, 30% of the radon progeny come in to contact with air passageways in the lung and adhere to the surfaces. The health impacts of radon and radon progeny are due to the radioactive emissions of the various elements as they decay. Of the three kinds of emissions – alpha, beta, and gamma – alpha particles are the most dangerous. (An alpha particle is a helium nucleus moving at high speed.) Alpha particles are large. And while they do not penetrate far, alpha particles have very high energy and can do considerable damage to cells, such as those near the surfaces of respiratory passages. Much of the radon ingested with water diffuses through the walls of the gut. Radon and its progeny can affect some cells in the stomach wall. However, because of the presence of food, much of the radiation is absorbed. Also, the exposure of the stomach and other organs in the digestive tract is limited. The quantity of water consumed in a day is much less than the quantity of air that is breathed.



Health impacts are thus mainly due to alpha particle emissions from radon in air and radon progeny. As the particles pass through matter, they knock electrons off molecules, causing them to be broken and changed. Some of the changes can be harmful to living tissue. For example, if the information in a DNA or genetic molecule is changed, the functioning of the whole cell can be altered, particularly when the cell reproduces itself. Genetic molecules in tissue are frequently broken by random processes caused by normal body heat and various chemicals in the body. Enzymes in the body are usually successful in repairing single strand breaks in the DNA double helix. However, if there are multiple and simultaneous breaks – caused, for example, by an alpha particle – the DNA may very well be put back together wrong with possible ill effects on the cell it governs.

Radon induced carcinogenic mechanism – Radon being a chemically inert gas can decay into active progenies that are electrically charged and can be inhaled when attached to natural aerosols, eventually reaching epithelial cells of our lungs. Once in the lung tissue, deposited radon progeny decays to generate alpha-particles, which damage DNA both directly and through generation of free radicals. With the decay of alpha-particles during the ejection of electrons from water, several reactive species are generated leading to cellular damage caused by hydroxyl radical attack. Cellular damage can also occur in nearby, non-irradiated bystander cells through the release of chemical by-products by irradiated cells. This 'bystander' effect can result in non-linear dose–response damage and underestimation of radon exposure risks. It is also possible that the lung tissue cellular injury from alpha particles is predominantly due to chromosomal damage in neighboring non-irradiated cells. Moreover, after exposure to alpha-particle radiation, observable levels of cytokines are detected in the supernatants of exposed cells, implying a possible effect of cytokines in radon-induced carcinogenesis.

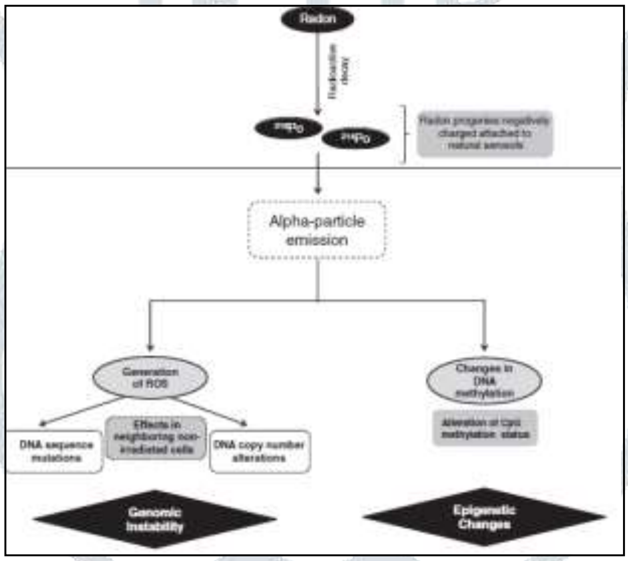


Fig 1: Radon Induced Carcinogenic Mechanism *Source: Hubaux, et.al (2012)*

Estimating Health Risks of Radon

There is no direct and conclusive evidence linking radon exposure in the home to increased incidence of cancer. Estimates of health risks from radon exposure have to be made on the basis of studies of people who have been exposed to high levels of radiation.

The counties of Alaska (10.7), South Dakota (9.6), Pennsylvania (8.6), Ohio (7.8), Washington (7.5), Kentucky (7.4), Montana (7.4), Idaho (7.3) have high levels of radon. The map shows the upper central as well as north eastern region have high radon concentration.

Data on the uranium miners has been found to be the most useful for estimating risks of "low-level" radon exposure in the home. Where workers in uranium and other mines have been exposed over long periods to high concentrations of airborne radon, they have had significantly higher lung cancer rates. For example, a study of mortality rates of 4,000 U.S. uranium miners found there were 135 lung cancer deaths (up to 1974) in excess of the 16 that would have been predicted for the group with normal rates.

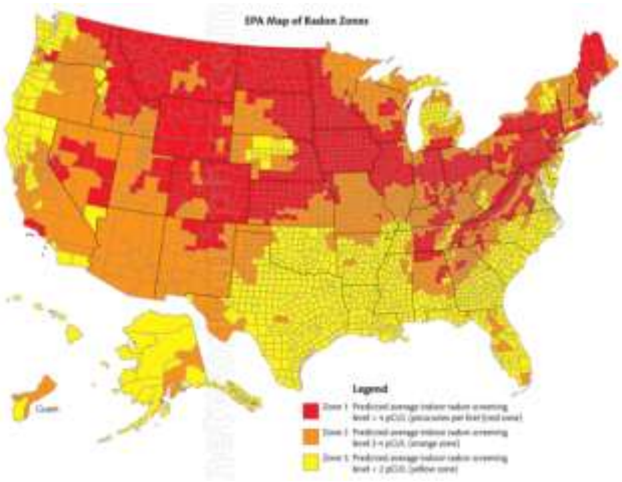
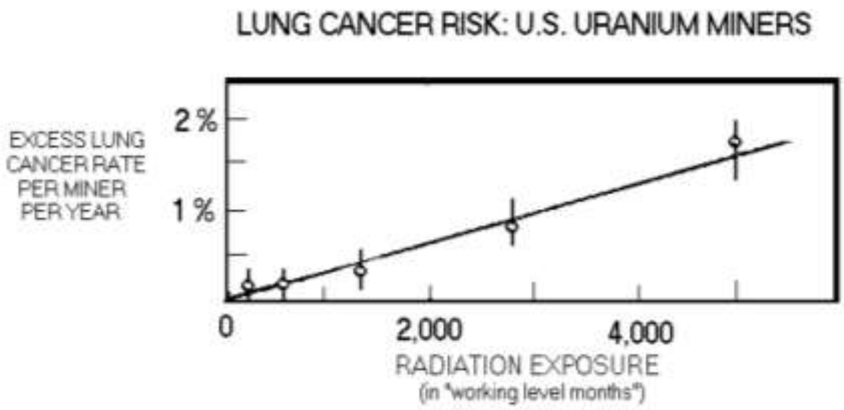


Fig 2: EPA Map of US Radon Zones *Source: epa.gov*

The study and graph below shows that, at high doses, excess lung cancer mortality rates have been proportional to radiation exposure. The studies also found there was a delay of from 10 to 15 years between the time of exposure and the appearance of lung cancer caused by such exposure.



Detection and Testing: To determine if your home is at risk of radon exposure, you can do several tests. One of which is through the indoor air radon test, which is inexpensive and can be bought at local home supply stores. Meanwhile, radon sampling on water requires a special laboratory or sampling technique to measure radon before it escapes the sample water.

The projection of health risks from high radiation exposures to low exposures involves certain assumptions that reflect scientific opinion rather than facts. Is the health risk from low-dose radiation simply proportional to known risks of high-dose radiation? Or is there a threshold below which radiation represents no health risks at all? For example, conclusions from the studies of uranium miners are fairly definite for radiation exposures over 500 rems (an exposure comparable to living for 60 years in a house with 10 pCi/L of radon in the air). There is evidence of excess lung cancer among miners down to the 40-50 rem exposure level, but knowledge of the health risks at these lower levels becomes increasingly ambiguous.

Scientists are left, then, with the necessity of making assumptions on how the known risks at high radiation levels should be projected down to low-dose levels. Majority opinion of scientists on a National Academy of Sciences committee favors a linear assumption for alpha-type radiation. The risk estimates given below are based on the linear assumption, but they should not be considered precise. The uncertainties are so great that the actual risks might double – or half – the estimated risks. Moreover, the health risks from radon may be multiplied when combined with exposure to other pollutants, such as those found in cigarette smoke. Such "synergistic" effects are not understood at this time.

Projected Health Risk:

Scientists and people in public health agencies agree that health risks from direct consumption of well water are generally of minor significance. It is the air that residents of a house breathe that provides the greatest exposure to radioactivity. There is a constant exposure in breathing air in contrast to infrequent ingestion of drinking water. Periodic, short-term exposure to concentrated airborne radon due to such water-agitating activities as dishwashing, laundering and showering may double overall exposure.

The risk of dying from lung cancer as a result of airborne radon is estimated to be 1-2% for each 4 pCi/L of lifetime exposure. For drinking water, it is estimated that there is an additional lifetime risk of dying from cancer (primarily stomach cancer) of 1-2% per 20 to 40 thousand pCi/L in the water, depending on house size and ventilation.

These risk estimates should be viewed with some caution. They are based on assumed projections of high-level radiation risks to low-level risks. In the case of air radon, the 'lifetime" exposure assumes 60 years and 100 years exposure in a closed house. In reality, of course, people spend time out-of-doors or away from their homes. Also, radon exposure is reduced when windows are opened in the summer or in bedrooms during sleeping hours. Nevertheless, radon levels in some Maine homes clearly represent significant health risks. In a recent study, 13.5% of household air samples had airborne radon levels of 4 pCi/L or more. A few were in the 100 pCi/L range; one house had 500 pCi/L of airborne radon.

In the case of waterborne radon, l2% of 3,000 Maine homes tested had levels over 20,000 pCi/L. Levels over 100,000 pCi/L have been found in 30 to 40 homes in Maine, and several homes had levels over 1 million pCi/L in their water.

In the early 1990's researchers at the University of Maine completed two studies on the contribution of domestic water use to indoor airborne radon exposure patterns. In the first of these studies, data from 68 homes was examined to determine the proportion of chronic airborne radon (and radon progeny) due solely to domestic water use. Comparison of radon levels to water usage show that water-derived airborne radon comprises, on average, about 32% of chronic domestic airborne radon levels. The balance comes mostly from radon in soil gas. In 14 of the 68 cases examined, radon from water use contributed more than 50% of the total airborne radon.

A second study examined acute exposure to radon. Acute exposure is short-term exposure to radon levels significantly above chronic levels, as may be experienced in a closed bathroom while showering. Monitoring radon levels in a closed bathroom (door closed, no vent fan) showed that within five minutes of initiating the shower, the level of radon in the bathroom began to climb rapidly. The radon level continued to climb until just after the shower was turned off, at which point the radon level stayed constant for approximately 15 to 20 minutes. About 75% of the radon in the water was released during the showering process. Increases in the amount of radon ranged from 2 to 114 pCi/L of air as a result of the shower.

One house produced acute exposures that doubled the chronic exposure. Additionally, the study found that small, respirable aerosols of water (breathable water droplets) were generated that contained up to 80% of the radiation contained in all aerosols in the bathroom. Two principal conclusions may be drawn from these studies, one optimistic and one pessimistic.

The good news is that treating radon-laden domestic water may be an especially effective means to reduce total radon exposure in homes because removing radon from water is relatively easy, it virtually eliminates acute exposure and significantly reduces average indoor airborne radon levels. The bad news is that the repeated, acute exposure that may occur during normal use of untreated, radon-rich domestic water may be cause for increased estimates of health risk due to radon exposure.

Action Level: The Maine Department of Human Services recommends that remedial actions be initiated where airborne radon levels exceed 4 pCi/L and water radon levels are above the 20,000 to 25,000 pCi/L range. The significance of health risks from radon in the home is up to the individual to judge. Certainly radon exposures greatly above the action levels suggested would represent significant health risks. At the other end of the scale, some people could be more affected by worrying about radon than by the radon itself. In the great majority of cases, there is no immediate urgency. Decades of exposure might involve significant risks, but generally not a few months or even years of exposure.

Risks from Radon compared to other Health risks:

Heart disease and cancer cause over half the deaths in the United States each year:

Total deaths (1993)	2,268,000
Heart disease	944,600
All forms of cancers	530,900
Lung and respiratory cancers	156,600
Radon – U. S. EPA estimate	14,000

All other causes	792,500

As the table shows, more than 6 out of every 100 deaths are caused by lung cancer. In Maine, the number of annual lung cancer deaths is about 900. Smoking is responsible for 80 – 85% of lung cancer deaths. Other causes of lung cancer include many chemicals found in industrial settings and, to a lesser extent, in homes. Radon is thus only one of a number of indoor air pollutants.

Radon is second only to smoking, however, as a cause of respiratory cancer. Asbestos ranks third as a cause, followed by the other indoor pollutants. The U.S. Environmental Protection Agency (EPA) estimates that living with 10 pCi/L in the air is equivalent to smoking one pack of cigarettes a day. Another EPA estimate places the number of deaths attributable to radon each year at 14,000, within a range of 7,000 to 30,000 due to uncertainties discussed earlier. People are exposed to many sources of radiation. However, as the chart shows, radon is the source of more than half of a typical individual's radiation dosage from common causes.

Radon is the number one cause of lung cancer among non-smokers, according to EPA estimates. Overall, radon is the second leading cause of lung cancer. Radon is responsible for about 21,000 lung cancer deaths every year. It may also be seen from the following figure that radon was the third leading cause of cancers in 2010 but it has ascended the cause of death table over the years that is a very worrying trend.

Fig 3: US Mortality for Selected Cancers *Source: epa.gov*

There is a smoker vs non smoker dichotomy in lung cancer causation and aggravation. This is true for radon exposure as well. Smokers are more vulnerable to radon related lung cancer risk since they are already in the risk group as compared to non-smokers. Therefore the synergistic effects of radon and smoking make smokers many times vulnerable to lung cancer. For this population about 62 people in a 1,000 will die of lung-cancer, compared to 7.3 people in a 1,000 for never smokers. Put another way, a person who never smoked (never smoker) who is exposed to 1.3 pCi/L has a 2 in 1,000 chance of lung cancer; while a smoker has a 20 in 1,000 chance of dying from lung cancer.

Table 1: Vulnerability Criteria of Smokers to Radon

Radon Level	If 1,000 people who smoked were exposed to this level over a lifetime*...	The risk of cancer from radon exposure compares to**...	WHAT TO DO: Stop smoking and...
20 pCi/L	About 260 people could get lung cancer	250 times the risk of drowning	Fix your home
10 pCi/L	About 150 people could get lung cancer	200 times the risk of dying in a home fire	Fix your home
8 pCi/L	About 120 people could get lung cancer	30 times the risk of dying in a fall	Fix your home
4 pCi/L	About 62 people could get lung cancer	5 times the risk of dying in a car crash	Fix your home
2 pCi/L	About 32 people could get lung cancer	6 times the risk of dying from poison	Consider fixing between 2 and 4 pCi/L
1.3 pCi/L	About 20 people could get lung cancer	(Average indoor radon level)	(Reducing radon levels below 2 pCi/L is difficult.)
0.4 pCi/L	About 3 people could get lung cancer	(Average outdoor radon level)	

Note: If you are a former smoker, your risk may be lower.
* Lifetime risk of lung cancer deaths from EPA Assessment of Risks from Radon in Homes (EPA 402-R-03-003).
** Comparison data calculated using the Centers for Disease Control and Prevention's 1999-2001 National Center for Injury Prevention and Control Reports.

Table 2: Vulnerability Criteria of Non-Smokers to Radon

Radon Level	If 1,000 people who never smoked were exposed to this level over a lifetime*...	The risk of cancer from radon exposure compares to**...	WHAT TO DO:
20 pCi/L	About 36 people could get lung cancer	35 times the risk of drowning	Fix your home
10 pCi/L	About 18 people could get lung cancer	20 times the risk of dying in a home fire	Fix your home
8 pCi/L	About 15 people could get lung cancer	4 times the risk of dying in a fall	Fix your home
4 pCi/L	About 7 people could get lung cancer	The risk of dying in a car crash	Fix your home
2 pCi/L	About 4 person could get lung cancer	The risk of dying from poison	Consider fixing between 2 and 4 pCi/L
1.3 pCi/L	About 2 people could get lung cancer	(Average indoor radon level)	(Reducing radon levels below 2 pCi/L is difficult.)
0.4 pCi/L		(Average outdoor radon level)	

Note: If you are a former smoker, your risk may be higher.
* Lifetime risk of lung cancer deaths from EPA Assessment of Risks from Radon in Homes (EPA 402-R-03-003).
** Comparison data calculated using the Centers for Disease Control and Prevention's 1999-2001 National Center for Injury Prevention and Control Reports.

Source: epa.gov

Regional Aspects of Radon

The World Health Organization (WHO) says radon causes up to 15% of lung cancers worldwide. In an effort to reduce the rate of lung cancer around the world, the World Health Organization (WHO) launched an international radon project to help countries increase awareness, collect data and encourage action to reduce radon-related risks. The U.S. EPA is one of several government agencies and countries supporting this initiative and is encouraged by WHO's attention to this important public health issue. It is due to the concerted efforts of EPA that radon related research is at a very advanced stage. There lies a great data anomaly on a worldwide scale as countries like USA and Canada use pCi/L while others use Bq/m^3. One Pci/L is equivalent to 37 Bq/m^3. Thus it would be pertinent to see the radon situation regionally.

World scenario: While the International Commission on radiation protection has set an accepted level of radon at 100 – 300 bq/m3, it may be seen from the corresponding figure, that since the data is a mean value, it is capable of showing data extremes like even 5000 bq/m3 in areas like United States. If the individual country data is analysed, it may be seen that the countries of North America like, United States, Canada and Mexico exhibit very high levels of radon concentration followed by Northern countries of Europe such as Sweden and Norway. Asia also has a high to moderate level concentration of radon as is shown in the map. The lowest is seen in parts of upper parts of Africa and whole of the continent of Australia. The following table shows radon concentration in few regions of the world:

Fig 4: World Radon Map, *Source: Science direct.org*

Table 3: Radon Levels at Different Locations

Country	Concentration (Bqm^{-3})
Mexico City	55
Spain	45
China	81
Bulgaria	99
Hungary	58
India (nationwide)	23
India (Kerala)	25

Source: Ramsiya, et.al (2017)

European Scenario: In a National level survey, it was seen that countries having highest concentrations of radon were Austria, Norway, Finland, Luxembourg, etc. as is seen in the map that upper parts mostly show red and yellow colour that corresponds to high and moderate levels of radon. While countries like Germany, Poland, United Kingdom had lower concentrations of radon. These findings corroborate that average radon levels in dwellings vary widely within and between countries. In most countries the world average of 40 Bq.m-3 is exceeded (1). Countries with mainly sedimentary soils (e.g. Germany, the Netherlands, Poland and the United Kingdom) present lower or equivalent averages, whereas those with old granite soils (e.g. Austria, the Czech Republic and Finland) are more prone to radon emissions. If a common action level of 200 Bq.m-3 were to be defined, Austria, the Czech Republic and Finland would have to take remedial measures for more than 10% of the houses, as against under 3.5% in countries with sedimentary soil, for example Poland and the Netherlands.

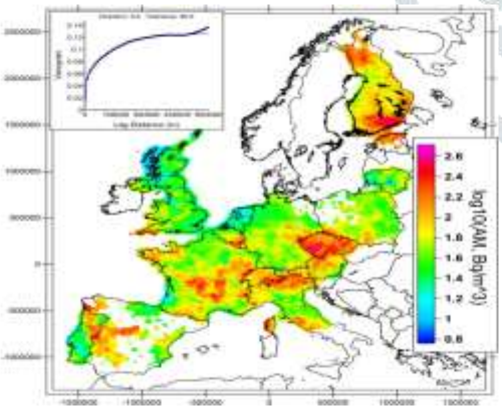


Fig 5: European Radon Map *Source: sciencedirect.com*

Indian Scenario: Although radon research in India is still at a nascent stage, as a result of which there exists a great dearth of national level statistics as well as geo mapping. Nonetheless some very illuminating studies have come up over the last few years that have pointed towards the increasing impact of radon on human health that have paved the way for deriving a national level picture.

A countrywide survey on radon and thoron levels has been carried out in Indian dwellings under a Coordinated Research Project sponsored by the Board of Research in Nuclear Sciences (BRNS), Department of Atomic Energy (DAE). An analysis of the data shows that the indoor radon gas concentrations at different locations vary between 4.6 and 147.0 Bq.m-3 with a geometric mean of 23.0 Bq.m-3. It is observed that the major contribution to the indoor inhalation dose is due to radon and its progeny. High indoor inhalation dose rates are observed at the northeastern region of India. The dependence of indoor radon levels on the dwelling types, examined statistically, has indicated significant differences between mosaic and wooden floors having plastered and whitewashed walls. A radon/thoron atlas of the country has been prepared using the data generated not only from this project but also from earlier surveys carried out by this Centre.

In another study, indoor radon concentration has been measured in Aizawl district, Mizoram, India, which has the highest lung cancer incidence rates among males and females in India. Simultaneously, radon flux emanated from the surrounding soil of the dwellings was observed in selected places. The annual average value of concentration of radon of Aizawl district is 48.8(22.65) Bq m^{-3} with a geometric standard deviation of 1.25(1.58). Measured radon flux from the soil has an average value of 22.6 mBq m^{-2} s^{-1}. These results were found to be much below the harmful effect or action level as indicated by the World Health Organisation. On the other hand, presence of higher radon levels in conjunction with food habit and high-level consumption of tobacco and its products in the district have been found to increase the risk of lung cancer incidence in the district.

In a very significant study of measurement of radon and thoron in dwellings of Palakkad, Kerala using nuclear track detectors, it was seen that radon and its progenies have a substantial contribution to natural background radiation. Long term exposure of such radiation increases the probability of occurrence of cancer at low to moderate levels. The present study covers 25 dwellings in Pirayiri region of the Palakkad district, Kerala, India, using twin cup based dosimeter. The data analysis shows that geometric mean of radon gas concentration (25.52 Bqm^{-3}) which is slightly higher than the nation wide average value of 23. The study also compared the study area radon concentration with other places in Kerala as is seen in the following table:

Table 4: Radon Concentration in Kerala Districts (2017)

Area	Radon concentration (in Bq/m^3)
Chavara	13
Thevalakkara	10
Karunagapally	12
Neendakkara	28
Thankassery	144
Pirayiri	28

Source: Ramsiya, et.al (2017)

It is interesting to note that the coastal belt of Kerala has an incidence of High Background Radiation (HBR) due to the presence of the radioactive monazite sand, although the relation between HBR and cancer incidence has not yet been established, but there is a high possibility of the high radon concentration in this region due to the presence of high radiation zones.

In another study where analysis of 30-month data of outdoor Radon activity at National Atmospheric Research Laboratory (NARL), Gadanki, India, was carried out. The detailed results show that Fast Fourier Transform (FFT) power spectrum of Radon has identified the presence of several energy peaks in the time series that range from 4 to 24 h indicating the periodicity at different time scales. This diurnal and seasonal trend in radon prove its strong correlation with meteorological parameters. A significant effect of precipitation on the radon concentration and its linear growth recovery after rainfall was observed. The mean radon activity over NARL for the study period was found to be 12.35 Bq/m^3. Hence, the composite seasonal cycle of Rn is concentrated and it is observed that the activity of radon is characterized by low concentrations in June through August and higher concentrations November through February.

Control Measure: As noted, the primary health risk is radon from the air. The key factors affecting airborne radon levels in the home are:

1. Radon levels in soil gas and type of construction where house and earth meet;

2. Radon levels in the well water and water-use habits; and

3. Ventilation rates of the house.

Soil gas can enter basements through dirt floors or cracks and other openings in the basement floor and foundation walls. Thus, the type of structure may be important, especially if the house is an old one. If a house or part of the house is built over a dirt-floor basement or unventilated crawl space, it may be exposed to excessive amounts of radon in soil gas.

Radon in well water can be released into the air of the home in the course of various water-using activities. The rate at which radon is released from water to the air depends upon the degree to which the water is aerated. When water is agitated, the radon is released as much as eight times faster than when the water is standing and not agitated. Thus, the frequency of use of showers can affect airborne radon levels. Laundry and dishwashing machines can affect airborne radon levels too.

Differences in air radon levels from one house to another have little to do with differences in ventilation rates. However, within a given house, there is an inverse relationship between air-change rates and airborne radon levels. Thus, a reduction in ventilation rate from, say, one air change per hour to one-half air change per hour would double airborne radon levels.

Ventilate House

- Ventilation is a control method primarily for situations where airborne radon is due largely to water rather than soil gas. In any event, sealing the basement should precede increasing ventilation.
- Tightly scaled houses, such as those with solar and energy efficient designs, may have high levels of airborne radon from radiation sources that are relatively low because of a low air change rate.
- The ventilation rate of a tight house can be increased significantly by cracking a couple of windows during the winter or installing an air-to-air heat exchanger.
- The cost of increased ventilation through cracking windows may be substantial. If a house were fairly well insulated and had one half air change per hour, adding another one-half air change would cut air-borne radon levels in half – but increase heating costs.
- The cost could be substantially reduced by ventilating certain rooms at certain times. Radon released in a closed bathroom during a shower can be largely prevented from entering the rest of the house by opening the bathroom window before opening the bathroom door – or through use of a ventilating fan.
- Heat losses can also be reduced significantly through use of an air-to-air heat exchanger. The units, which range from small window-mounted units to large floor-mounted units, can save up to 70% of the heat in the air exhausted to the outdoors.
- Increasing the air-change rate for a house – either by cracking some windows or using air to air heat exchanger – will reduce levels of all indoor air pollutants.

Seal and Ventilate Basement or Crawl Space

- Due to wind passing over a house and the pull of combustion air for heating or of ventilating air, the air pressure in a basement is usually higher than that in the soil surrounding the foundation. This pressure difference can cause large quantities of soil gas to be sucked through openings in the foundation.
- Major openings in foundations, such as drains or sump-pumps are easily recognized, but small cracks and openings in the basement floor and foundation walls can be difficult to detect.
- Un-trapped basement drains have been found to be a significant source of radon in some regions. The cost of sealing or rerouting a drain, or installing a water trap probably involving some tearing up of concrete and replacement of a few sections of pipe will vary greatly from one house to the next.
- Epoxy paint or other polymeric coatings in multiple layers can be used to seal porous or cracked basement surfaces. However, rough areas in the surface should first be caulked and smoothed, so that there are no openings the paint cannot fill. The cost of sealing basement surfaces – by painting a basement with polyurethane, for example – is quite low under $100 for materials.
- A vent fan, used in conjunction with an air-to-air heat exchanger, can draw air into a basement from the outdoors to counteract air pressure differences.
- Air pressures can also be balanced by ventilating the area under the basement floor. This is done by a vent that draws air from under the basement floor and releases it to the outside.
- Adding ventilation to a tightly sealed crawl space (through vents) is not costly, although the resulting heat loss might be. Sheets of plastic can be put beneath floors to reduce radon diffusion and the infiltration of cold air. However, to be effective, there must be no openings or cracks through which the radon can bypass the plastic.

Radon Treatment: Remember that if there is radon in the water, it also means that it enters the house through the soil or basement. As such, it will be the predominant source of water in your house. Thus, if you treat your water source with radon, you can also eliminate radon problems in the air. You must remove the radon in water before it becomes airborne. Devices termed 'point-of entry treatment' are installed on the devices to treat water resources before entering your home.

Granular Activated Carbon (GAC): One method to remove radon in the water is through the granular activated carbon (GAC) unit. Nowadays, there are various units available with different models, sizes, and types; however, they all follow the same technique in removing radon. These GAC units have a fiberglass tank with granular activated carbon. This unit is made of a fine material that can trap and hold the filtered radon. Since the carbon has a fine particle size, it can quickly clog the sediments or other contaminants found in the water. Meanwhile, there are GAC units that include a special backwashing inclusion that can remove the sediment. However, this backwashing feature can reduce the effectiveness of the activated carbon to remove the radon.

Thus, eliminating the sediment filter or sediment source placed on the GAC tank is one of the best protection that you can have to prevent clogging. Various estimates suggest that GAC should only be used on water supplies with a maximum radon concentration of less than 30,000 pCi/L.

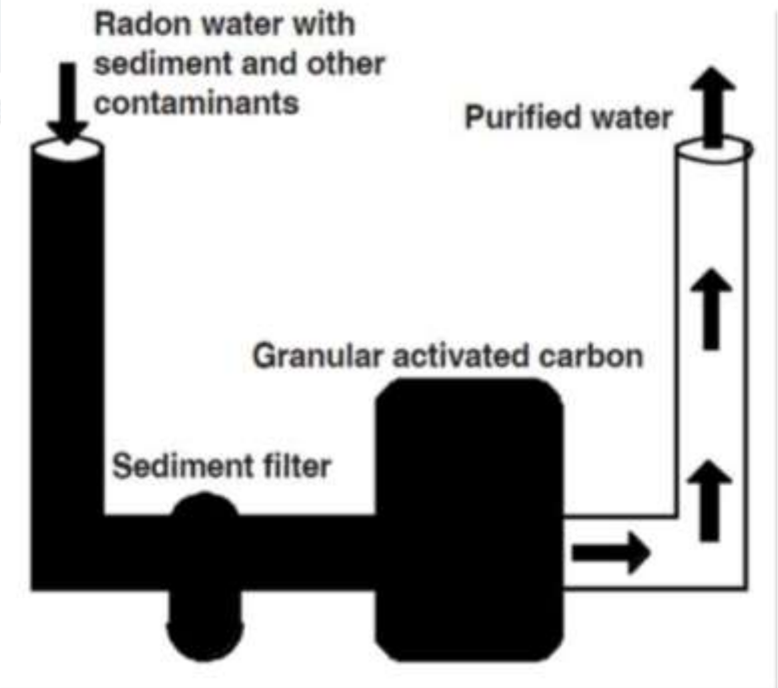
After you are done with testing your water, you must check the GAC filters that have high removal efficiency rates according to the level found in the water. If you have finally decided to buy a unit, choose a filter size that matches your water condition and daily water use.

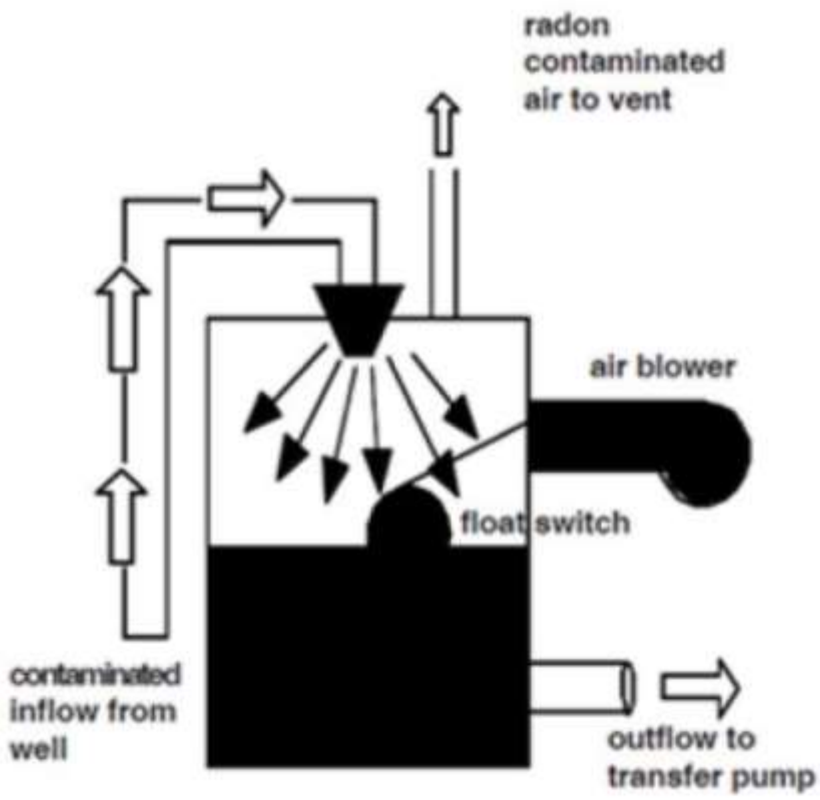
According to the standards set by the EPA, a three-cubic-foot unit can handle about 250 gallons of water each day and reduce the levels of radon. The typical daily use of water inside the home can range from 50 to 100 gallons each person daily. One of the major drawbacks of using the GAC filters in the removal of the radon is that it can cause an eventual build-up of radioactivity within the GAC filter. As such, you should place the GAC unit in an isolated part of your house, like in the basement, to prevent exposure.

Also, you have to replace the carbon annually to reduce the dangers of having accumulated radioactivity. Meanwhile, those GAC filters that are used for radon removal need to be disposed of immediately. You can ask for help from professionals regarding the proper disposal of the used GAC filters. GAC treatment units are also installed inside the home to remove petroleum, chlorine, pesticides, odours, and various products in the water. In these examples, the GAC filter may accumulate radioactivity as it removes the radon in the water. With this in mind, one should always test the water and see if it has radon. It should be considered a health hazard that must be removed by the GAC filters.

Home Aeration Units

The home aeration units is one of the best technology available today that can remove radon in the water. It can agitate the water physically and allow the dissolved radon gas to be vented and collected outside. With the current innovation in home aeration units, it can remove about 99.9% of radon on it. If you wish to install home aeration units, other quality issues of the water must be taken into account. This includes the levels of manganese, iron, plus other contaminants. If your water is high on these types of contaminants, they may need to be pre-treated so that they won't clog the aeration unit. Also, you can use disinfection equipment since some of the aeration units will not allow bacterial contamination in the water system.

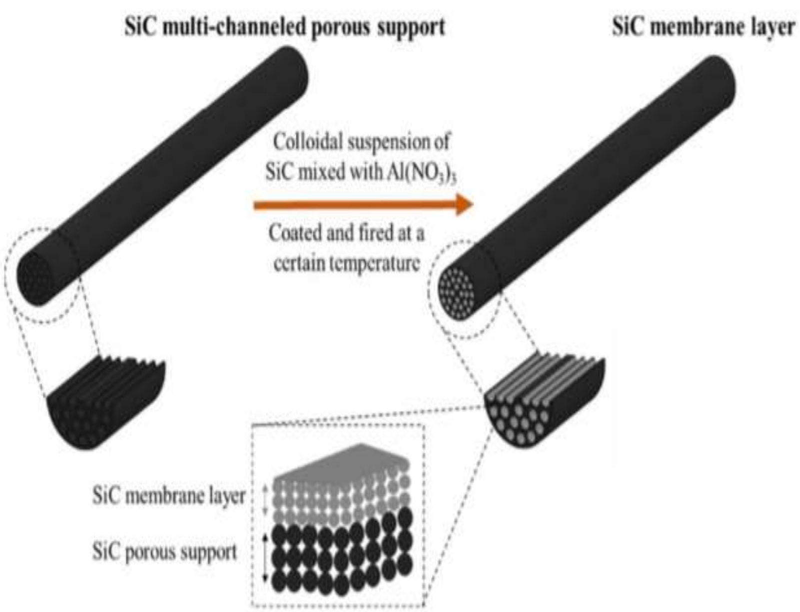




Various aeration treatment units are available nowadays. However, they all function on the principle that aerating or agitating the water will enable the radon gas to escape to vent and capture. Each of the units has advantages and disadvantages. One of the common aeration styles is a spray aeration unit. In this style, the water that contains radon is sprayed in the tank through a nozzle. The increased surface area of the sprayed water droplets will cause the radon to come out of the water in the form of a gas, while the air blower will carry the radon gas to a vent located outside your home.In the initial spraying, about 50% of the radon only will be removed. As such, you need to spray the water several times to increase the removal efficiencies. To have a supply of the treated water, you must use a large holding tank or a 100-gallon tank. Another aeration unit to try is the packed column, wherein the water will pass through a thin film with inert packing material inside the column. With this, the air blower will force the radon contaminated air located at the back of the column to an outdoor vent.

If the column is high, it can remove about 95% of radon in the water. Then, the final stage of the aeration system uses a shallow tray that will contact the water and the air. Water will be sprayed into the tray, and it will flow on the ashtray as the air is sprayed up through the tiny holes located on the bottom. As such, it can remove more than 99.9% of radon in the water, and it vents outside of your home.

Silicon Carbide (SiC) membranes can be used for filtration of radon from water. Key advantages of SiC membranes include their chemical resistance, high temperature stability and low fouling behaviour. Hence SiC-based filters can easily handle water contaminated with Radon at elevated temperatures and are resistant to chemical cleaning. In addition, they have been shown to exhibit high flux compared to polymeric and other ceramic membrane materials. The membrane pore size is tailored through controlling various process parameters during manufacturing. SiC membranes with various pore sizes have been studied for the filtration of varied concentration of Radon in water. For both synthetic produced water and produced water sourced from conventional and unconventional sources, SiC membrane technology promises a smaller carbon footprint, an overall more compact system and reduced usage of chemicals. These advantages also make SiC membranes attractive for water treatment applications in specific area where water is contaminated with Radon.



Risk Related to Radon Contaminant in Air & Water:

Regulation: Currently, no federal law or regulation enforces the standard level of radon in drinking water. The EPA has proposed to set a rule to regulate the level of radon in the drinking water from the municipal water suppliers or those water systems that cater to more than 25 households a whole year-round. The EPA does not regulate the water wells managed privately. The EPA has proposed that municipal or community water suppliers provide clean water with radon levels that are not more than 4,000 pCi/ L. As such, and it only contributes up to 0.4 pCi/L of radon inside your home.

With this requirement, it is assumed that the State also takes action to reduce radon levels indoors by developing EPA-approved air units. It also includes an enhanced indoor air program by the State called the Multimedia Mitigation Programs.

Most of the radon that you breathe comes from the ground beneath your house. With this option, the State can focus its efforts on resolving bigger problems by encouraging the public to fix radon issues inside their homes and prevent them from entering. With the proposed regulation, those States that did not wish to develop their indoor air programs are required to reduce radon levels in their community water systems of up to 300 pCi/L.

With this amount of radon in the water, it will contribute only about 0.03 pCi/ L of radon to the air inside your home. Even if a State does not develop and approve of an enhanced indoor air program, private homes may choose water systems with a local radon program and produce drinking water of 4,000 pCi/L. This has been proposed by EPA under the framework of the 1996 Amendments to the Safe Drinking Water Act. With this, the overall risks of people from radon on both air and water will be reduced.

Conclusion

Many research works have resulted in definitive evidence of an association between residential radon exposure and lung cancer. In addition, the radon health risks predicted by occupational studies of underground miners who breathed radon for a period of years have pinpointed the health concern associated with radon gas. People who smoke and are exposed to radon are at a greater risk of developing lung cancer. EPA recommends taking action to reduce radon in homes that have a radon level at or above 4 picocuries per liter (pCi/L) of air by using radon detection kits. In addition, remedial measures that are necessary to tackle the radon situation would be to reduce radon exposure wherever possible, to improve household ventilation, stop smoking inside residences, seal ground level cracks on floors with proper plastering. Strategies against radon rely on radiation detectors and implementation of radon-resistant features; for example, houses in potentially high exposure zones should be equipped with pipes to vent radon gas generated in the ground, and sealed with plastic sheeting and caulking. Ideally, active mitigation techniques involving physical alterations such as sub-slab depressurization should be instigated, as these methods are more effective.

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