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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

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"College on Atmospheric Boundary Layer and Air Pollution Modelling"
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"Radon"

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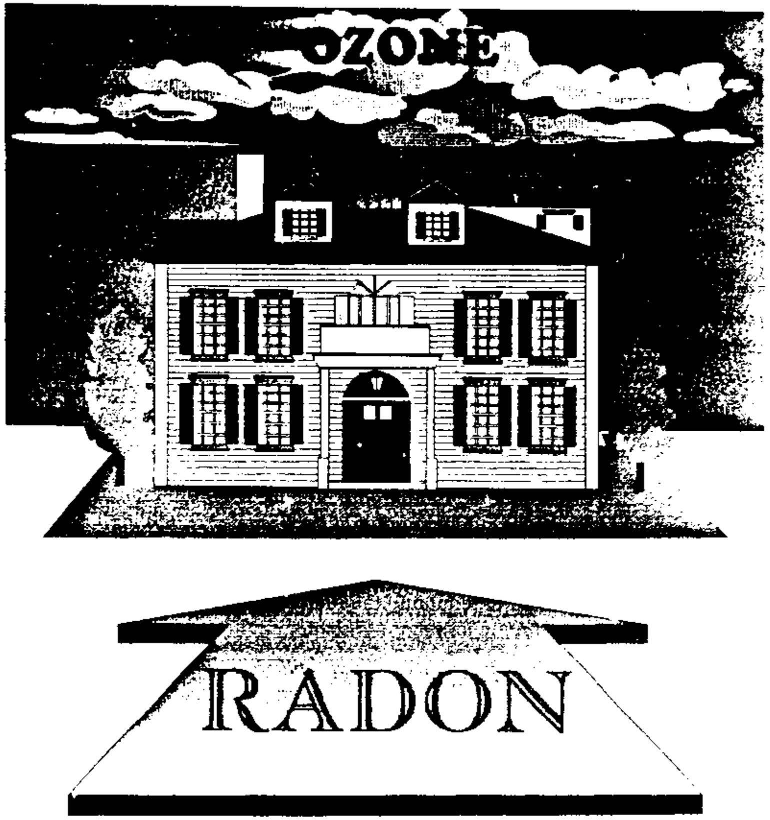
The University of Michigan School of Public Health Presents:

Air Quality Workshop

A faculty workshop on the issues of radon and ground level ozone



urgeon General Health Advisory: *Indoor radon is a national health blem. Radon is the second leading cause of lung cancer, causing thousands of eaths each year. Millions of homes have elevated radon levels.*

R. A. Deininger

RADON AND LIFE

WHAT IS RADON?

Radon is a naturally-occurring radioactive gas formed by the radioactive decay of materials naturally present in the earth's crust. Radon cannot be seen, felt, or otherwise detected by the senses. Nevertheless, high concentrations of radon can have a negative effect on human health. In particular, people who are exposed to high radon concentrations have an increased risk of lung cancer. This effect is magnified in people who smoke.

Because radon is a risk to human health, it is important to understand what radon is and what it can and cannot do. In this and the following units, students will be introduced to concepts needed to understand radon and radon risks.

Background

1. Vocabulary

Atomic number: An experimentally-determined number characteristic of a chemical element that represents the number of protons in the nucleus, which in a neutral atom equals the number of electrons outside the nucleus and that determines the place of the element in the periodic table.

Nuclear force: The strongest force found in nature, which is found only in atomic nuclei and serves to bind protons and neutrons together.

Radioactive: Possessing the property of spontaneously emitting alpha or beta particles or gamma rays by the disintegration of the nuclei of atoms.

Bequerel: A quantity of radioactive material which undergoes one nuclear transformation, or decay, per second.

Curie: A quantity of radioactive material which undergoes 3.7×10^{10} nuclear transformations per second.

Half-life: The time required for half of the atoms of a radioactive substance to disintegrate.

Radiation: Energy that is radiated in the form of waves or particles. Radiation resulting from the decay of radioactive materials forms a subset of all naturally occurring radiations.

Photon: A quantum, or small packet, of radiant energy having no mass and propagating in wave form. Gamma rays, x rays, radio waves, and visible light are all composed of photons.

Alpha particle: A positively-charged nuclear particle identical with the nucleus of the helium atom that consists of two protons and two neutrons and is ej ted at high speed in certain radioactive transformations.

Beta particle: A high-speed electron ejected from the nucleus of an atom during radioactive de ay.

Gamma ray: A photon or radiation quantum emitted spontaneously by a radioactive substance.

Decay products: Elements resulting from the radioactive decay of a specified radioactive atom.

Radioactive progeny: Decay products which are themselves radioactive and which disintegrate in turn to form other elements

2. Background information

The radon atom is very large. It has 86 protons, 136 neutrons, and 86 electrons. The atomic number of an atom reflects its protons only, and so radon has been assigned the atomic number 86. The weight of all the protons and neutrons makes radon atoms 222 times heavier than the smallest atom, which is hydrogen. (86 protons + 136 neutrons = 222. The electrons contribute a very small amount to the total weight of the atom.)

Radon is a radioactive atom. All radioactive atoms have unstable arrangements of protons and neutrons in their nuclei. Some of the biggest atoms are radioactive because they are just too big to hold together. Other atoms are radioactive because their nuclei contain either too many protons or too many neutrons.

Some radioactive materials, like radon, are found in nature. Radioactive atoms can be found in the rocks, in the soil, in the air, and even inside the human body. The presence of naturally-occurring carbon-14 in people, animals, and plants permits archaeologists to determine the age of bones and other remains by examining their content of radioactive materials. Natural radioactive materials are seldom considered to be a problem unless they become trapped or concentrated in some way.

Radioactive material becomes stable by disintegrating or decaying. Each type of radioactive material has its own unique half-life. The half-life is the time it takes for half of the radioactive atoms in the material to decay. The half-life of radon is 3.8 days. If you have a certain quantity of radon on a given day, you will have half as much after 3.8 days. After a second 3.8 days have passed, you will have half of that half left, or a quarter of the original amount. This process continues forever, since you can continue to divide the amount left over by two and never reach zero. By the time ten half-lives have passed, however, there is so little left that the remainder can be considered zero for practical purposes.

The half-life of radon is very short compared to that of uranium, which is 4.5 billion years. The half-life is important because that time interval determines the time available for radon and its decay products to be dispersed into the environment. The 3.8 day half-life is sufficient to allow radon gas to move several meters in soil. Material with a short half-life may deliver a very concentrated radiation dose, since it is decaying rapidly.

Radioactive atoms give off radiation. Radiation can be made up of particles or photons. Photons are packets of pure energy. Nuclear radiation, radio waves, visible light, and ultraviolet light are all examples of photons.

The alpha particle is the largest particle. It is made up of two protons and two neutrons. It has a charge of +2. Alpha particles are typically given off when large nuclei (such as radon) decay. A oversized nucleus can get smaller fast by giving off alpha particles. Alpha particles are low in penetrating power due to their large size and charge. They can be stopped by a sheet of paper, or by the dead cells which form the outermost layer of skin on the body. However, alpha particles can cause a great deal of damage if they are not shielded from living cells. This is what occurs when radon and other alpha emitters are taken into the lungs.

The beta particle is much smaller than the alpha particle. It is the same size as an electron, and it has the same negative charge. A beta particle is given off when a nucleus has too many neutrons, and attempts to become stable by converting a neutron into a proton. Beta particles can travel through greater thicknesses of material than alpha particles can; however, a single beta particle causes only about 1/20th the tissue damage that an alpha particle can cause.

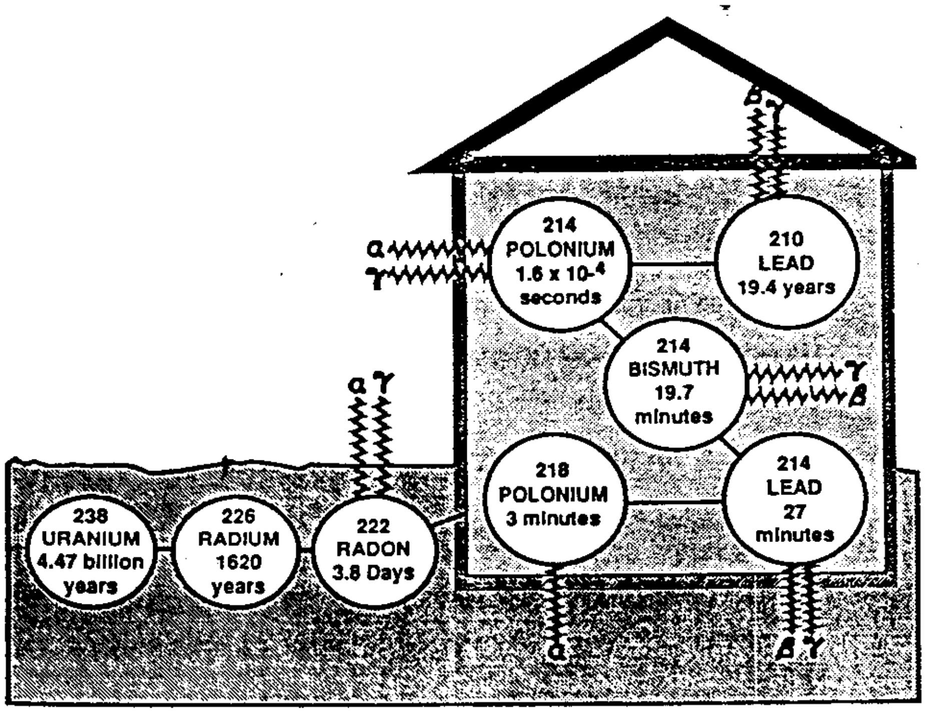
Gamma rays are photons which are given off whenever the nucleus has too much energy. Sometimes an unstable nucleus cannot get rid of enough energy by emitting particles, and it therefore emits photons as well. Gamma rays can travel all the way through the body and keep going afterwards. Gamma rays are far less important to radon effects than are alpha particles. Because they have no charge, they are less likely than alphas or betas to interact in matter over short distances.

Radon itself can be found everywhere, indoors and out. It is formed when even heavier atoms of uranium decay by emitting alpha particles. Since uranium is present in rocks and soils everywhere, and since it has a half-life of 4.5 billion years, radon has been around for a long time and will be around for a lot longer. The earth is assumed to be approximately 5 billion years old. This means that there is half of the uranium left that was here when the earth was formed.

Radon is an inert gas, meaning that it is chemically inactive. Since it is not chemically bound or attached to other materials, it can move around easily through the soil and through other materials with pores or cracks. Radon disperses in air and can be inhaled. Because it is inert, it does not interact with the material of the lungs, and most of it will be exhaled.

Radon also decays into other decay products which have much shorter half-lives. When radon decays, it is transformed into polonium-218, another alpha emitter. Polonium -218 and subsequent radon decay products (progeny) are not gasses. These decay progeny are solids particles which that can easily attach themselves to solid objects such as dust, smoke, floors, walls, or any other object. When these particles are suspended in air like dust or smoke, they can be inhaled. These solid particles are likely to remain in the lungs, where they continue to decay and emit radiation. Most of the damage caused by radon is really due to radon progeny.

URANIUM DECAY CHART



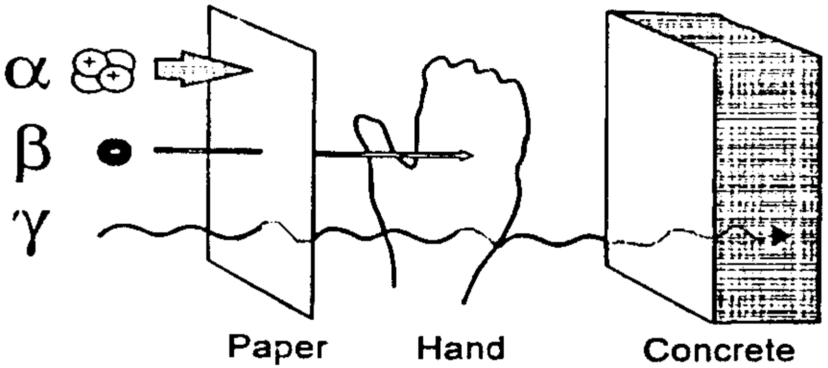


Figure 5: Penetrating properties of radiation

Radon Risk If You've Never Smoked...

Radon Level	If 1,000 people who never smoked were exposed to this level over their lifetime...how many would get lung cancer....	The risk of cancer exposure compares to..
20 pCi/l	About 8 people	←Risk of being killed in a violent crime
10 pCi/l	About 4 people	
8 pCi/l	About 3 people	←10 times the risk of dying an an airplane crash
4 pCi/l	About 2 people	←The risk of drowning
2 pCi/l	About 1 person	←The risk of dying in a home fire
1.3 pCi/l	Less than 1 person	(Average indoor radon level)
0.4 pCi/l		(Average outdoor radon level)

Radon Risk If You Smoke...

Radon Level	If 1,000 people who smoked were exposed to this level over their lifetime...how many would get lung cancer....	The risk of cancer exposure compares to .
20 pCi/l	About 135 people	←100 times the risk of drowning
10 pCi/l	About 71 people	←100 times the risk of dying in a home fire
8 pCi/l	About 57 people	
4 pCi/l	About 29 people	←100 times the risk of dying in an air plane crash
2 pCi/l	About 15 people	←2 times the risk of dying in a car crash
1.3 pCi/l	About 9 people	(Average indoor radon level)
0.4 pCi/l	About 3 people	(Average outdoor radon level)

RESOURCE DOCUMENT

RADON ENTRY & BEHAVIOR

A. Introduction:

The first unit in this series introduced the concepts of radiation, radioactive decay and their relationship with radon. The second unit discussed the health effects associated with radon and its progeny (daughter nuclides). Now that the students have some understanding of what radon is and why it is bad, it is time to discuss how and why it can enter our homes and schools and what it does once it gets there. Some of the concepts that will be introduced are transport mechanisms, pressure differentials and concentration gradients, the various radon sources, soil, water and construction materials and the various entry pathways into the home.

B. Objectives:

After completion of this unit the student should understand the following:

1. The basic conditions required for radon to enter a structure:
    a. A radon source
    b. A transport mechanism
    c. An entry pathway
2. Various mechanisms by which radon moves about within the structure
    a. Mechanical equipment; Furnaces, fans, heaters, etc
    b. Concentration gradients

C. Background Information:

1. Vocabulary:
    a. Transport Mechanism: The process involved in moving something from one place to another.
    b. Differential Pressure: A driving force generated across a medium when it is subjected to different pressures.

    c. Diffusion: The passive movement of gas through a medium from an area of greater concentration to an area of lesser concentration.
    d. Concentration Gradient: The differences in concentration along a pathway from higher to lower concentrations.

2. What is radon?

Radon is a colorless, odorless gas produced by the radioactive decay of a Uranium-238 atom. This decay process goes through several stages, eventually producing Radium-226. Radon-222 is produced by the alpha decay of Radium-226. The decay of Radon and its subsequent daughter products produce alpha particles. These high-mass, high energy particles can either kill or mutate (alter) lung cells, if they decay within the lung. It is these mutated cells that can eventually lead to the formation of lung cancer.

3. Radon Sources

There are three principal sources of radon found in indoor air: 1) rocks and soils under the building, 2) building materials used in construction, and 3) radon dissolved in the water supply. Of these sources the rocks and soils under the building are by far the most important. Some kinds of rocks, and the soils that form from their breakdown, are more likely to giving off radon than others. This is because some rocks contain more uranium than others, especially some granites, marine shales, and some limestones.

D. What Causes Radon to Enter the Home?

There are three requirements for radon entry into buildings: 1) a nearby radium source, 2) a transport mechanism, and 3) entry points into the building.

1. Radium Sources

Radium is a common element found in many soils and bedrock. Radium is widely dispersed, however, only a small amount is required for an indoor radon problem to develop. As a result, low level problems have been found in all 50 states.

2. Transport Mechanism

There are four transport mechanisms that bring radon into houses: 1) Air pressure differentials between outside and inside air, 2) radon diffusion from soil to indoor air, 3) well water, and 4) the release of radon from a source of radium inside of the house.

a.) Air Pressure Differentials

Radon entry by pressure driven airflow is the dominant entry mechanism in the majority of buildings with elevated radon levels. When air is forced out of the house , air pressure differentials between the inside and outside air are created. This results in air being pulled into the house to replace the air that has left. When the house is depressurized in this way, air enters through cracks and holes located over the entire building shell. In this situation, the house substructure is under negative pressure, and creates a suction on the surrounding soil. It is estimated that between 5 and 20 percent of the infiltrating air enters from below ground level and can carry radon in with it. Other effects that can induce this phenomenon are temperature, wind, indoor mechanical devices and rain.

b.) Concentration Gradient Diffusion

Radon will diffuse through the soil from higher concentrations to lower. The highest concentrations will be near the radon source and will decrease in a spherical gradient. The more porous the soil, the faster the radon will diffuse. As a result, the soil concentrations will become uniform. Since the concentration at the surface of the soil is lowest, the concentration gradient is largest in that direction. This causes radon to not only flow upwards, but also into one's home. This occurs even when there is no or very little air transfer (i.e. winter time).

c.) Well Water

Radon dissolved in groundwater is released in gaseous form when exposed to air. With a drilled well, the water drawn has very little access to air; consequently, any radon emitted into this water will remain there until it decays or has the opportunity to be released in air. This opportunity comes in the form of water usage in the home, such as showering or washing clothes or dishes. Since the volume of water used by an average family each day is small compared to the volume of air in the house, it takes very high concentrations of radon in water to produce an airborne radon problem.

d.) Materials Within the Home

If radium is already present in the house, it requires no more elaborate transport mechanisms or entry route other than its decay to emit radon. Although materials containing radium are not the most common sources of elevated levels of radon in buildings, it does happen occasionally. Some materials that have been found in some instances to be sources of radon in buildings are: 1)concrete and concrete products made from uranium mine tailings, 2) earth-based building materials containing radium, 3) fireplaces constructed of radium-bearing stone, and others.

3. Entry Pathways

Any crack, fissure, or hole is a possible entry point for radon. The larger the hole, the greater the potential of radon gas entering the home.

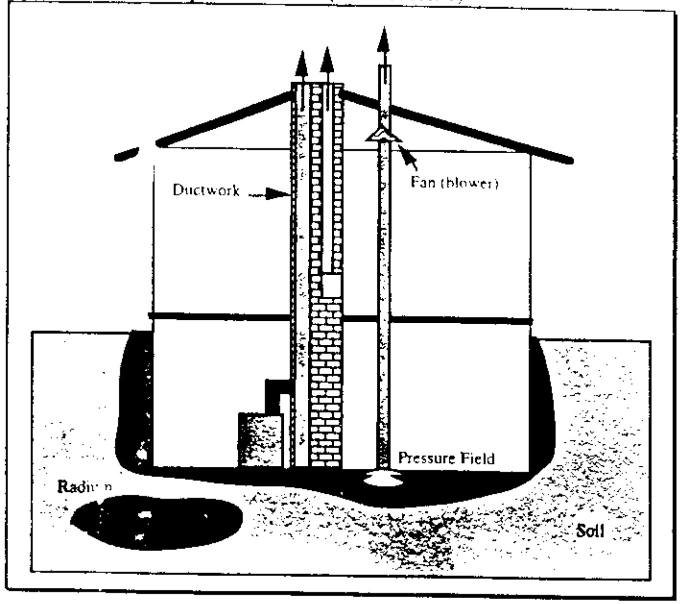
2. Preventing Entry

When hazardous levels of radon are not present in a building, it is beneficial to prevent this problem from ever originating. The following techniques are suggested for installation.

a. Soil Depressurization

Radon is pulled inside the basement of the house when the air pressure inside the house is lower than it is outside in the soil. Fans are used to reverse the pressure gradient creating a suction under the basement slab or crawlspace (a small area under the home). When the radon- rich air is vented to the outside it will no longer be a problem. A typical soil depressurization system will have a fan (or blower), a pipe system (also called ductwork), suction points, sealing (caulking), and a warning system. The most important feature of this mitigation design is to extend the low pressure field around as much of the house as possible. Putting this pressure field around the house is the most effective type of mitigation method, but is rather complicated and should be done by a licensed mitigation contractor. This method is also called "sub-slab suction system".

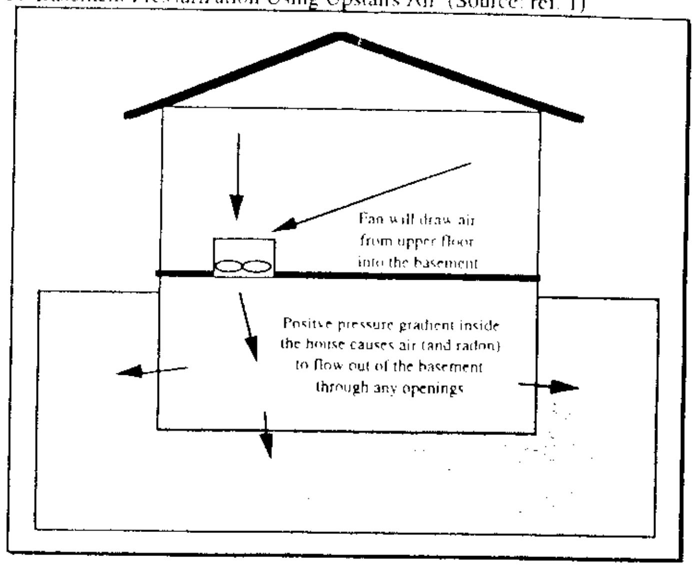
FIGURE 2: General Soil Depressurization (Source: ref. 1)



b. Basement pressurization

This mitigation technique accomplishes the same task as soil depressurization with the strategy reversed. Rather than depressurizing the soil around the basement, the basement itself is pressurized. This method pulls air from the upper floors of the house, and blows it into the basement causing the basement to have a positive pressure gradient. Having a positive pressure gradient on the inside of the house will cause the air to flow out of the house. This can be easily done by installing small fans between floors. However, care should be taken upon selection of size of fan, installation and location.

Figure 3: Basement Pressurization Using Upstairs Air (Source: ref. 1)



When this mitigation strategy is used, care should be taken not to draw air from the garage or any other room which may contain potential damaging combustion devices. It could be damaging to blow auto exhaust or any other hazardous hydrocarbons into the basement.

TABLE 4-7

Comparison of Pollutant Standard Index (PSI) Values, Pollutant Levels, and General Health Effects

	Pollutant level						Health	
PSI value	TSP (24-hr) µg/m³	SO_2 (24-hr) µg/m³	CO (8-hr) mg/m³	O_3 (1-hr) µg/m³	NO_2 (1-hr) µg/m³	Descriptor	Effects	Warning
400 and above	875 and above	2000 and above	46.0 and above	1000 and above	3000 and above	Hazardous	Premature death of ill and elderly. Healthy people will experience adverse symptoms that affect their normal activity.	All persons should remain indoors, keeping windows and doors closed. All persons should minimize physical exertion and avoid traffic.
300–399	625–874	1600–2099	34.0–45.9	900–1099	2260–2999	Hazardous	Premature onset of certain diseases in addition to significant aggravation of symptoms and decreased exercise tolerance in healthy persons.	Elderly and persons with existing diseases should stay indoors and avoid physical exertion. General population should avoid outdoor activity.
200–299	375–624	800–1599	17.0–33.9	480–899	1130–2259	Very unhealthy	Significant aggravation of symptoms and decreased exercise tolerance in persons with heart or lung disease, with widespread symptoms in the healthy population	Elderly and persons with existing heart or lung disease should stay indoors and reduce physical activity.
100–199	260–374	365–799	10.0–16.9	240–479	NR	Unhealthy	Mild aggravation of symptoms in susceptible persons, with irritation symptoms in the healthy population.	Persons with existing heart or respiratory ailments should reduce physical exertion and outdoor activity.
50–99	75ª–259	80ª–364	5.0–9.9	120–239	NR	Moderate		
0–49	0–74	0–79	0–4.9	0–119	NR	Good		

NR = No index values reported at concentration levels below those specified by "alert level" criteria (Table 5-1).

ª Annual primary National Ambient Air Quality Standard.

Source: United States Environmental Protection Agency, "Guideline for Public Reporting of Daily Air Quality—Pollutant Standards Index," 450/2-76-013. Washington, D.C., 1976.