RADON RESEARCH IN MULTI DISCIPLINES: A REVIEW

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Session 2, January 18, 2007

COURSE OUTLINE

I. Fundamentals of radon physics: review
II. Radon research in geology
III. Radon research in radiation biology
IV. Radon research in medicine
V. Radon research in health physics
Earth & Planetary Science
Radon research in multi disciplines - summary
Student Presentations
Radioactivity Laboratory demonstration

DETAILED COURSE WORK

The course work involves the following:

1. **January 17, 18, 19, 22, 25 1-3 PM**
   5 sessions each of 2 hours - 25%
2. **Study assignments -4 - 20%**

3 Project
   Literature Survey – Writing a report - 30%

4. **Project Presentation - 25%**

Required percentage to pass this course is 95%
Grading: P/F

Session 2

Radon & Geology

Session 2 January 18, 2007
Objective 1 of 3

1. Radon Geology

1.1 Distribution of uranium and radon sources in rocks and soils

1.2 Formation and movement of radon in rocks and soils

1.3 Radon entry from the soil and the water system into buildings.

2. Some examples of current radon research in rocks and soils:

2.1 Emanation of Radon-222 from soils, sub soils and sedimentary rocks.

2.2 Transportation parameters of radon: diffusion, viscous flow and type of soil, relationship to indoor air quality

Session 2 January 18, 2007

Objective 2 of 2

2. Some examples of current radon research in rocks and soils (continued):

   2.3 Characterization of sources, range and environmental effects of Radon-222 and its progeny.

   2.4 Soil radon gas as a probe to map geological profiles and tectonic discontinuities

   2.5 Correlation studies of soil radon gas variation with seismic activity in earthquake predictions

3. Study assignments

4. Selection of Student Project - Discussion of Presentation and Report

1. Radon Geology

Studies of the geology of radon mainly consist:

- distribution of uranium and radon sources in rocks and soils,
- radon formation and movement in rocks and soils,
- radon entry into buildings from the soil and water.

Ref:

Otton, J. K., Gundersen, L. C. S., Schumann, R. R., The Geology of Radon,
http://energy.cr.usgs.gov/radon/radonhome.html;http://energy.cr.usgs.gov/radon/georadon/3.html

1.1 Distribution of uranium and radon sources in rocks and soils

Uranium: The source

To understand the geology of radon – focus on

- location of formation,
- way of formation ,
- way of transportation .

But always first

begin with its parent source **URANIUM**.

1.1 Distribution of uranium and radon sources in rocks and soils …

URANIUM – The Parent

- Uranium is a primordial element.
- Uranium exists in almost all rocks.
- Uranium in most rocks may be in small levels – 1 and 3 parts per million (ppm) of uranium.
- Uranium content of a soil is dependent on the uranium content of the parent rock.

1.1 Distribution of uranium and radon sources in rocks and soils …

Uranium in rocks

- Uranium may be **higher** than average range of 1-3 ppm in some rocks.

- These consist of:
  - **volcanic rocks**,
  - **granites**,
  - **dark shales**,
  - **sedimentary rocks** that contain phosphate,
  - **metamorphic rocks**

Sedimentary rocks, some for example:
About 300 ppm of U in phosphorites,
About 20-30 ppm of U in bentonites and bauxites

Metamorphic rocks:
Metamorphic means altered or changed.
Metamorphic rocks may be derived from the above rock types.

- Layers of rocks high in uranium are beneath various parts of the United States.

1.1 Distribution of uranium and radon sources in rocks and soils …

Uranium in rocks …

Expectation
Higher uranium level in an area leads to higher levels of indoor radon – usual expectation.

However

- Some houses on **uranium-rich** soils have low levels of indoor radon.
- Some houses on **uranium-poor** soils have high levels of indoor radon.

Hence

- **Additional factors affect** the indoor **radon** levels in addition to uranium beneath the soil.

House – Soil – Air Radon

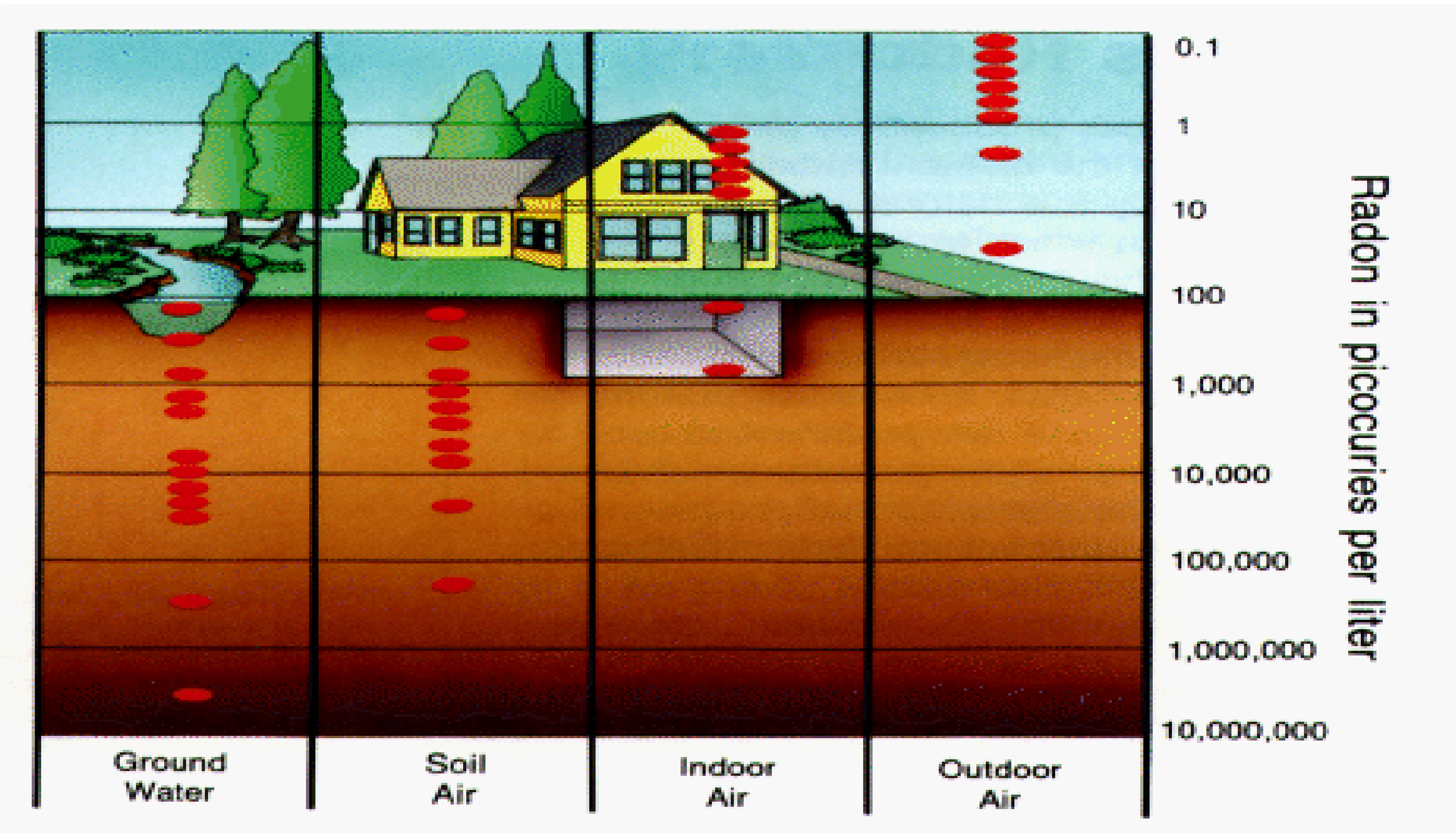


Figure by courtesy of USGS

1.2 Formation and movement of radon in rocks and soils

Radon formation

Uranium is present in all rocks and soils.

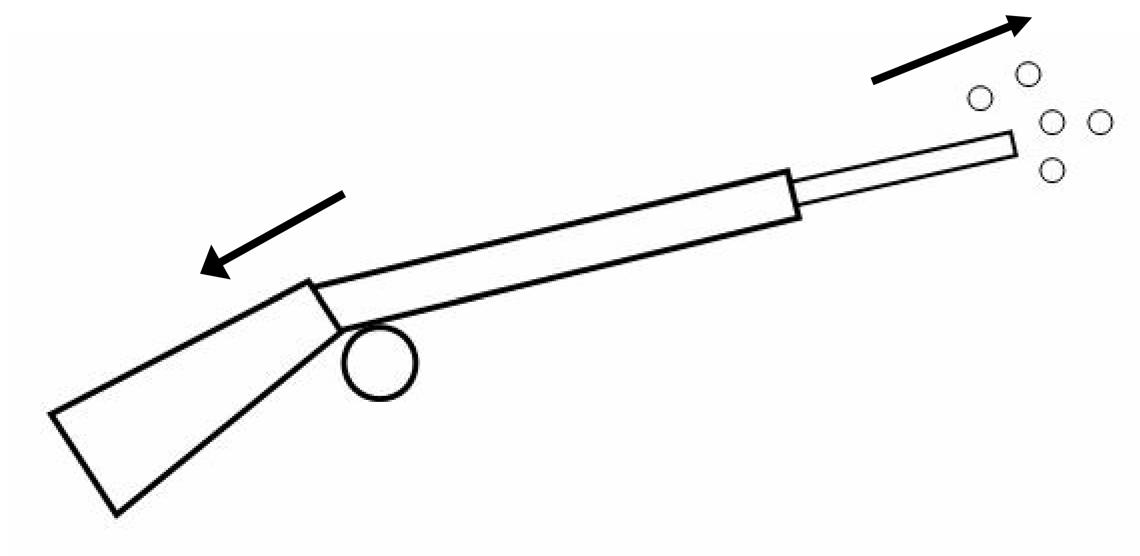
Radium and radon are daughter products are formed by the radioactive decay of uranium.

So they are present too!!!

1.2 Formation and movement of radon in rocks and soils …

Radon formation …

- "Each atom of radium decays by ejecting from its nucleus an alpha particle composed of two neutrons and two protons. As the alpha particle is ejected, the newly formed radon atom recoils in the opposite direction, just as a high-powered rifle recoils when a bullet is fired."



1.2 Formation and movement of radon in rocks and soils …

Radon formation …

Radon atoms are generated by the decay of radium.

But all radon atoms may not enter the pore space between the mineral grains where radium is located in the rock (or soil).

The chances of the newly created radon atoms entering the pore spaces of the grains depend

not only on the **proximity of the radium atom** to the surface mineral grain
but also on the **direction of the recoil of the radon atom** toward the surface of the grain.

1.2 Formation and movement of radon in rocks and soils …

Radon formation …

- **Unsuccessful**

1) Location deep within the big grain:

When radium atoms are present deep within a big grain, then direction of recoil of radon atom has no effect, the radon atoms will remain embedded in the mineral. Radon from the grain will not escape outside, into the pores,

2) Direction of recoil toward the grain’s core:

When the direction of recoil is toward the grain's core, the recoil will send the radon atom deeper into the mineral, even when a radium atom is near the surface of a grain.

1.2 Formation and movement of radon in rocks and soils …

Radon formation …

Successful

1) Recoil of some radon atoms directed toward the grains core;
2) Radium atoms are near the surface of a grain.

When this happens, the newly formed radon leaves the mineral and has a chance to enter the pore space between the grains or the fractures in the rocks.

1.2 Formation and movement of radon in rocks and soils …

Radon formation …

- Alpha recoil is the most important factor affecting the release of radon from mineral grains.

- The recoil of the radon atom is strong reaction. Most of the times, the newly formed radon atoms enter a pore space, cross all the way through the pore space, and become lodged in nearby mineral grains.

- **If the pore space contains water, the radon atom slows very quickly and is more likely to stay in the pore space.**

- 10 % - 50 % of the radon produced actually escapes from the mineral grains and enters the pores, for most soils.

- Most soils in USA contain between

  0.33 and 1 pCi of radium per gram of mineral matter

  200 - 2,000 pCi of radon per liter of soil air

1.2 Formation and movement of radon in rocks and soils …

Radon Movement …

Radon is a gas, so

- **greater mobility than uranium and radium fixed in rocks and soils.**

Radon is a gas, so

- **easier movement away from the rocks and soils**
- **easier escape into**
  - **fractures and openings in rocks**
  - **pore spaces between grains of soil.**

1.2 Formation and movement of radon in rocks and soils …

Radon Movement …

The parameters of radon's movement through soils:

- **MOISTURE CONTENT:**
  The amount of water present in the pore space
- **POROSITY:**
  The percentage of pore space in the soil.
- **PERMEABILITY:**
  The "interconnectedness" of the pore spaces that determines the soil's ability to transmit water and air.

1.2 Formation and movement of radon in rocks and soils …

Radon Movement …

Radon can move through cracks in rocks and through pore spaces in soils.

Radon moves more rapidly
through permeable soils,
such as coarse sand and gravel,
than through impermeable soils,
such as clays.

1.2 Formation and movement of radon in rocks and soils …

Radon Movement …

- Radon moves **slower in water** than radon in air.
  For example, before it completely decays, radon moves
  < 1” in **water-saturated rocks or soil**,
  > 6’ – tens of feet in **dry rocks or soils**.

- The reason for this is, mainly that, water moves slowly through soil pores and rock fractures than does air.

- Before its complete decay, radon travels **shorter distances in wet soils than in dry soils**.

1.2 Formation and movement of radon in rocks and soils …

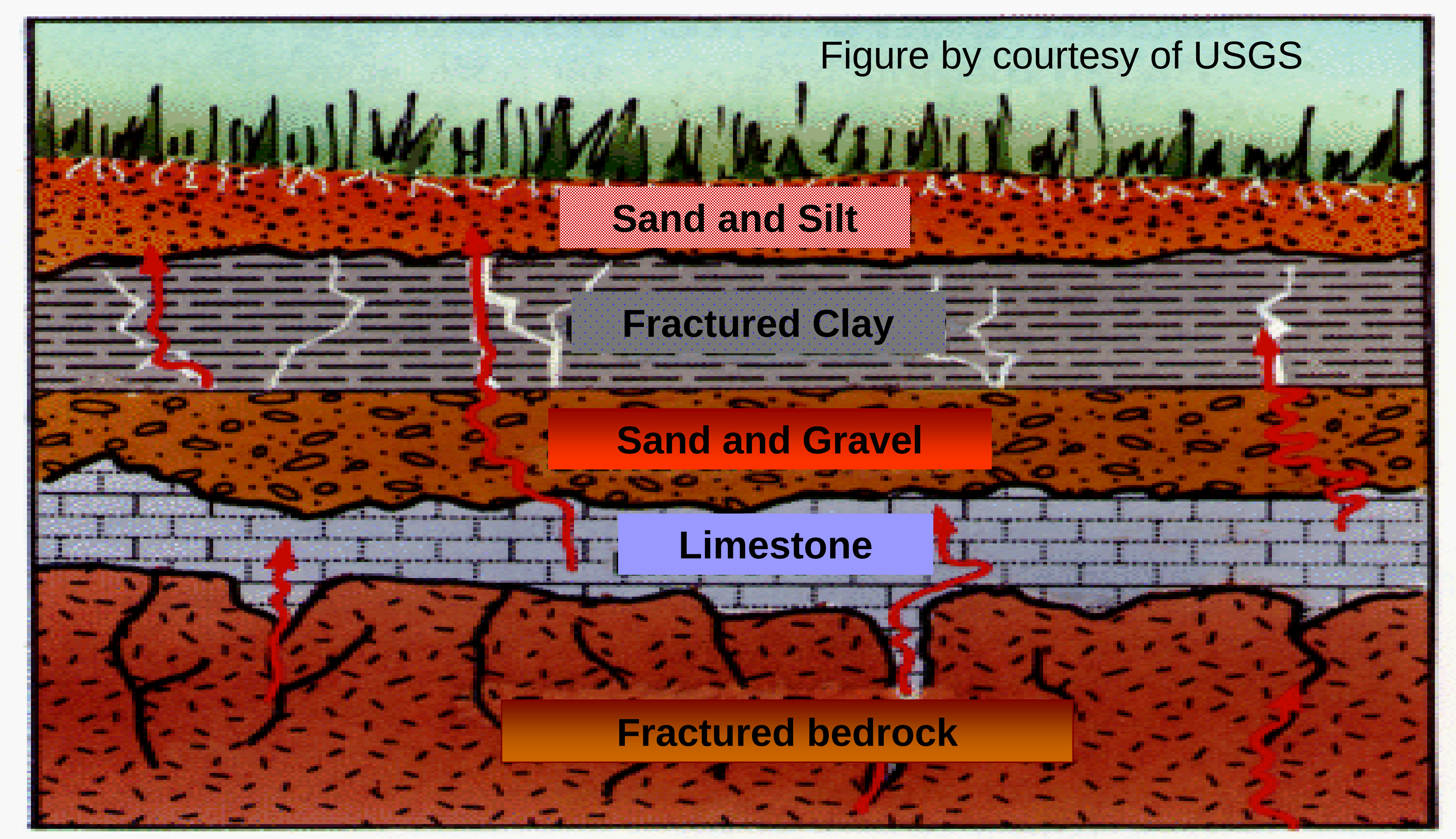
Radon Movement …

Reasons for high indoor radon

- **Drier**, highly **permeable soils,**
  bedrock such as
  hill slopes, mouths and bottoms of canyons,
  coarse glacial deposits, and fractured
  or cavernous bedrock,
  contribute to **high levels of indoor radon.**

- Even, "normal" range (200-2,000 pCi/L,
  with high permeability of these areas
  contribute to **high levels of indoor radon.**

Radon movement



1.3 Radon entry from soil and water system into buildings

Radon Entry Into Buildings

Radon gas usually escapes into the atmosphere after the formation in the soil and rock; while moving through soil pore Spaces of the soil and fractures of the rocks near the surface of the earth as shown in the figure labeled Radon Movement.

However, the reasons for soil air flow toward a house foundation are:

- differential air pressure between the soil and the house,
- The existence of openings in the foundation of the house,
- increased in permeability around the basement if present.

1.3 Radon entry from soil and water system into buildings

Radon Entry Into Buildings …

Air pressure around most houses is often

$>$ Air pressure inside the house.

Air moves easily from the gravel bed into the house through openings in the house's foundation.

All house foundations have openings :

- **cracks,**
- **utility entries,**
- **seams between foundation materials,**
- **uncovered soil in crawl spaces,**
- **unfinished basements.**

1.3 Radon entry from the soil and the water system into buildings …

Radon Entry Into Buildings …

Out door radon is generally quite low.

Most houses draw < 1% of their indoor air from the soil; the remainder comes from outdoor air.

Most houses draw < 20 % of their indoor air from the soil, with low indoor air pressures, poorly sealed foundations, and several other entry points for soil air.

Hence, even if the soil air is only at moderate levels of radon, levels inside the house may be very high.

1.3 Radon entry from soil and water system into buildings …

Radon Entry Through Water

Radon can also enter home through the water system.

- **Most of the radon escapes into the atmosphere, so water in rivers and reservoirs contains very little radon.**
- **So those who use surface water, do not face a radon problem from their water usually.**
- **City water processing is done by large municipal systems, aerating the water, allowing radon to escape, and delaying the use of water until most of the remaining radon has decayed.**

1.3 Radon entry from soil and water system into buildings …

Radon Entry Through Water

- Elevated levels of radon in ground water will be seen in areas of uranium-rich soils and rocks such granites in various parts of the United States.
- The small public water works and private domestic wells with closed systems and short transit times do not remove radon from the water or allow enough time for complete decay.
- In such cases, when people take showers, wash clothes or dishes, or otherwise use water, radon escapes from the water to the indoor air.
- A very rough rule of thumb for estimating the contribution of radon in domestic water to indoor air radon is that
- Water with **10,000 pCi/L** of radon : **1 pCi/L** of radon in the indoor air.

2. Some examples of recent radon research in rocks and soils

2.1 Emanation of Radon-222 from soils, sub soils and sedimentary rocks.

2.2 Transportation parameters of radon: diffusion, viscous flow and type of soil, relationship to indoor air quality

2.1. Research on radon emanations

Radon emanation depends on soil type and surface uranium concentration.

The emanation power of soil increases with moisture. For water content above 10% the radon emanation power of soil is about twice as high as for dry soil.
Median values observed are:
0.2 for dry soils and stones,
0.06 for sand,
0.025 for bricks,
0.006 for ceramic tiles,
0.008 for mineral slag,
0.3 for gypsum.

Ref:
Bossew, P.,
Research on the radon emanation power of building materials, soils and rocks
Appl Radiat Isot. 59(5-6):389-92, Nov-Dec 2003.

2.2 Indoor radon – Transport parameters

Radon gas concentrations in dwelling areas are dependent on

- radon concentrations in soil pores
- the radium content of the soil,
- emanating power for radium,
- soil moisture content.

The transport of radon from soil to the indoor living space depends on radon gas

- diffusion and viscous flow in the soil
- transfer rate to the building interior
- accumulation in cavities and cracks below and surrounding areas of the foundations of buildings.
- atmospheric pressure fluctuation,
- thermal gradients in fractured rocks, and
- air instabilities due to temperature differences allow air of high radon content to reach living space in dwellings in
- additionally any emanation which comes directly from building materials
- and any other sources

Ref:

Wilkening M.,Radon transport in soil and its relation to indoor radioactivity.
Sci Total Environ. 45:219-26, 1985.
Nazaroff WW.,Radon transport from soil to air,
Reviews of Geophysics 30(2): 137-160, 1992.

2.3 Identification of Radon 222 and its decay products in residential environments

- Radon 222 and its decay products in residential environments are identified.
- Pressure-induced flow of soil gas is the main cause of transport of radon from the ground into dwellings in some areas.
- Analysis of measurements of concentrations in U.S. homes has provided
  - information on distribution of indoor levels and
  - influence of geographic location.
- Experiments provided information on the limitations and merits of mitigation by air cleaning devices for removal of particles and radon decay products.

Ref:
Nero A.V., Sextro R.G., Doyle S.M., Moed B.A., Nazaroff W.W., Revzan K.L., Schwehr M.B. , Characterizing the sources, range, and environmental influences of radon 222 and its decay products., Sci Total Environ. 45:233-44, Oct 1985.

2.4 Radon probe for geological fault exploration

- Radon mapping is found to be useful for exploration of near and sub-surface geological faults. Radon concentrations seemed to be usually higher over the fault regions.
- Soil gas radon monitored in five active fault sites in northern and northwestern Greece, showed spatial anomalies.
- Soil gas radon is also monitored to study the correlation with earthquakes.

Ref: Physics Department Research Group, University of Greece.

2.5 Indoor radon in volcanic region – Spain

Observation:

Higher radon levels are found in houses built on the volcanic region than dwellings on non-volcanic area.

Facts:

- The soil of the area is not particularly uranium-rich.
- Some of the volcanic materials present very high permeability and therefore radon entering the houses might have moved long distances.

Possible explanation after the research study:

Radon may be possibly coming from the degassification of mantle through active faults.

Ref:

Baixeras, C.; Bach, J.; Amgarou, K.; Moreno, V.

Radon levels in the volcanic region of La Garrotxa, Spain, Radiation Measurements, 40(2-6):509-12; Nov 2005.

2.6 Radon in water and soil in volcanic region - Mexico

Objective: To study the effect of volcano eruption on soil gas radon and radon in water near high risk volcano region near Southeast of Mexico.

Observations:

- Groundwater radon showed no relation with the eruptive stages of the volcano.
- Soil radon levels were low, thus implying moderate degassing diffusion through the flanks of the volcano.

Ref:

Segovia, N.; Armienta, M. A.; Valdes, C.; Mena, M.; Seidel, J. L.; Monnin, M.; Pena, P.; Lopez, M.B.E.; Reyes, A.V., Volcanic monitoring for radon and chemical species in the soil and in spring water samples, Radiation Measurements 36(1-6): 379-83; Sept. 2003.

IAP 2007 12.091 Radon Research in Multi Disciplines

Study Assignments

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Session 2

Current radon research in building and building materials:

Do literature survey, read and write briefly on

- Radon dose from ceramic tiles
- Radon dose from clay bricks
- Radon emanation of building material
- Radon transport and the effect of moisture in concrete

Session 3

Study and provide salient features of

BEIR IV Report – Executive Summary

BEIR VI Report – Executive Summary

Session 1

1. List/locate Uranium, Thorium and Actinium Series in the Periodic Table.
   Explain the significance of these decay chains.
   Identify radon, thoron and actinon isotopes.
   Ref: Handbook of silicate rock analysis by Phil Pott

2. List all the isotopes of Radon and their half-lifes

3. Browse and list some radon publications from the website www.epa.gov

4. Study and comment on the radon potential of Texas, USA.

Session 4

Write brief reports on health effects of radon from studies in:

1) Geology
2) Health Physics
3) Medicine

References & Further Reading

- Baixeras, C.; Bach, J.; Amgarou, K.; Moreno, V.
  Radon levels in the volcanic region of La Garrotxa, Spain,
  Radiation Measurements, 40(2-6):509-12; Nov 2005.

- Clamp, G. E.; Pritchard J.
  Investigation of fault position and sources of radon by measurements of U-238 decay series radionuclide activity in soil samples,
  Environmental Geochemistry in Health 20; 39-44, 1998.

- Kenski, J.; Klingel R.; Schneiders H,; Siehl A.; Wiegand J.
  Geological structure and geochemistry controlling radon in soil gas,
  Radiation Protection Dosimetry 45 (1/4): 235-239, 1992.

References & Further Reading

- Kraner, H. W.; Schroeder, G. L.; Evans R. D.
  Measurements of the effects of atmospheric variables on radon-222 flux and soil gas concentrations. In
  : Natural Radiation Environment, pp 191-215,
  Eds: Adams, J. A. S.; Lowder, W. M.
  Chicago: University of Chicago Press, 1964.
  ISBN: 0226005968

- Nazaroff, W. W.,
  Radon transport from soil to air,
  Reviews of Geophysics 30(2): 137-160, 1992.

- Otton, J. K., Gundersen, L. C. S., Schumann, R. R.,
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- Segovia, N.; Armienta, M. A.; Valdes, C.; Mena, M.; Seidel, J. L.; Monnin, M.; Pena, P.; Lopez, M.B.E.; Reyes, A.V.,
  Volcanic monitoring for radon and chemical species in the soil and in spring water samples,
  Radiation Measurements 36(1-6): 379-83; Sept. 2003.
- Winkler R.; Ruckerbauer F.; Bunzl K.
  Radon concentration in soil gas: a comparison of the variability resulting from different methods, spatial heterogeneity and seasonal fluctuations,
  Sci Total Environ. 72(1-3): 273-82, May 14, 2001.
- http://omega.physics.uoi.gr/radon/English/services.htm
- http://omega.physics.uoi.gr/radon/English/services.htm#Radon%20and%20faults