

Radioactivity

Lecture 17

Radioactivity in Buildings

Building Materials

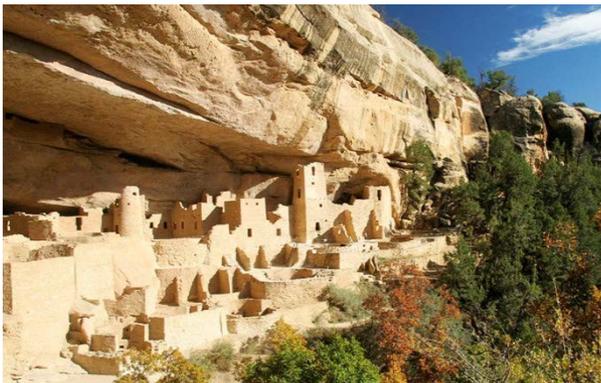
Modern commercial buildings are constructed from steel, glass and stone, modern residential buildings from glass, stone and wood, stone and wood.

The radioactivity level in buildings is directly correlated with the radioactivity of its materials and the quality of its ventilation system!



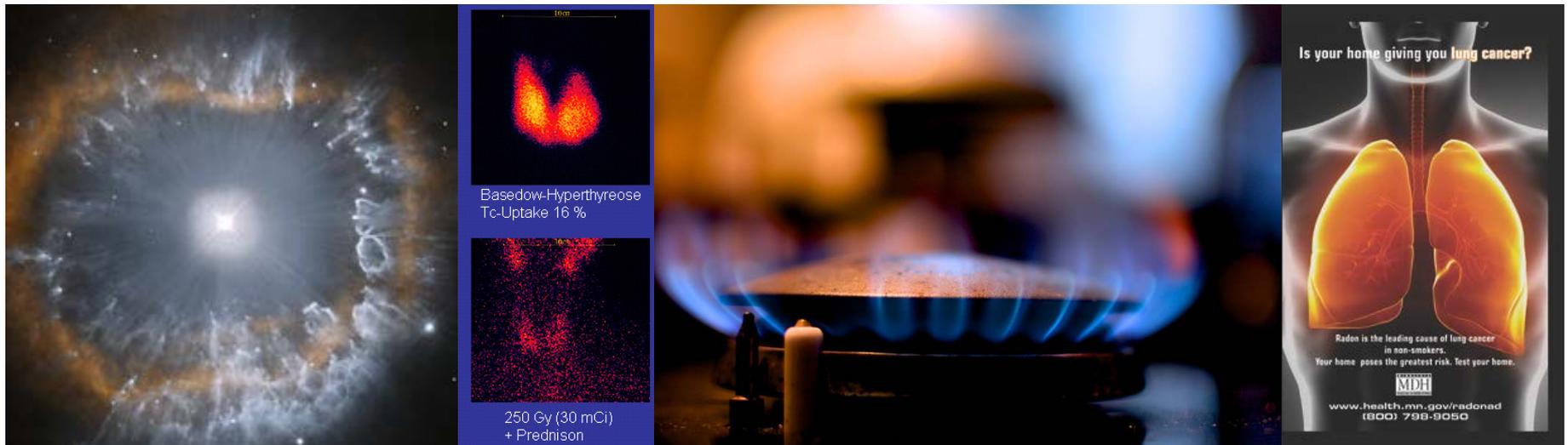
Release of Radiation in building materials

Most building materials are of natural origin, they contain the natural fraction of radioactivity, slightly altered or modified by the preparation process. Building materials therefore count as TENR since the natural radioactivity, mostly from quarries is transferred into the human living environment. This always has been the case since the beginning of mankind living in caves, cliff dwellings, clay and stone buildings to modern residential homes.



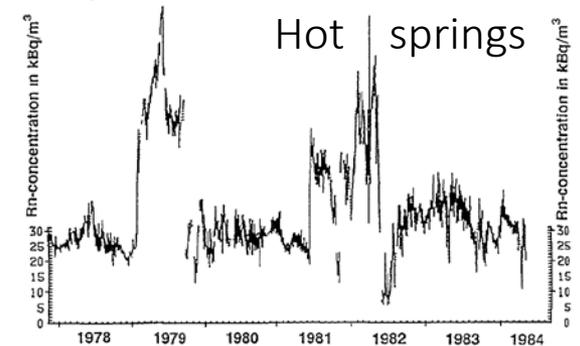
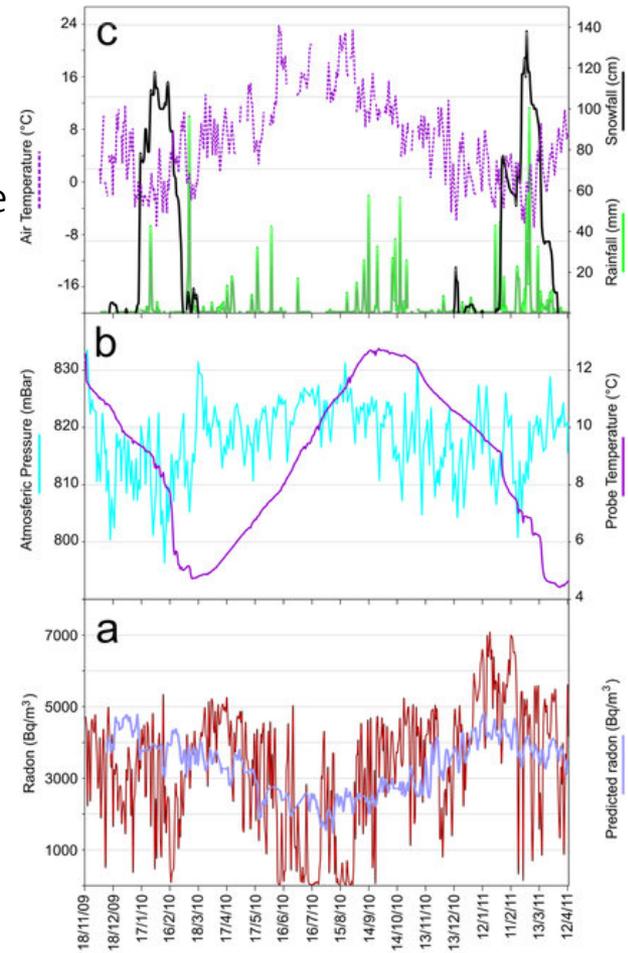
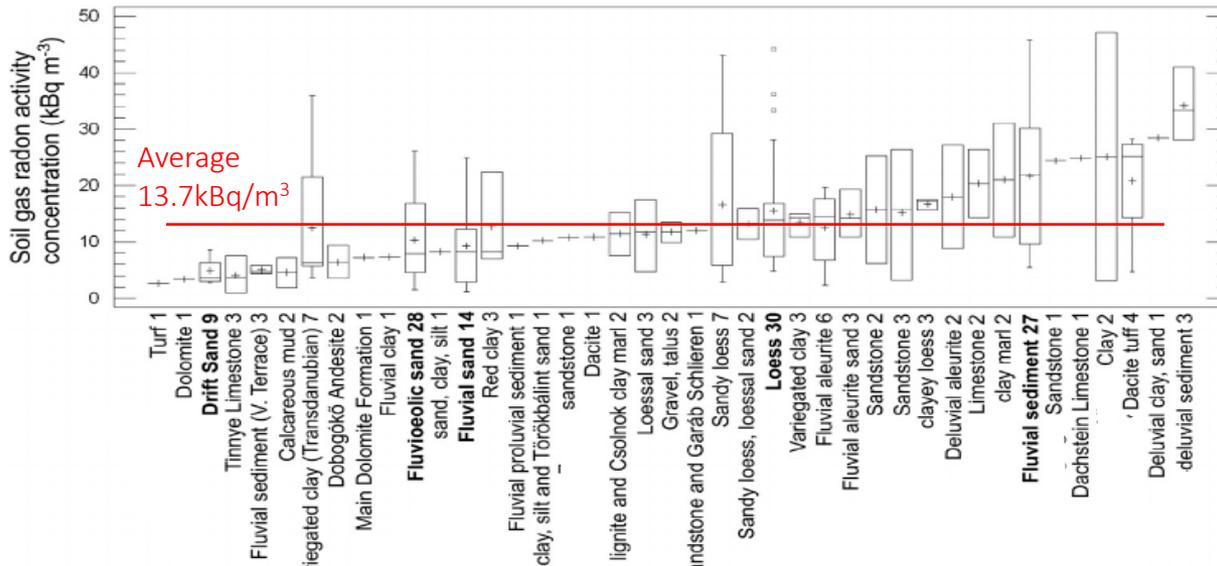
Radon in Buildings

There are two naturally occurring elements Technetium $_{43}\text{Tc}$ and Radon $_{86}\text{Rn}$ that don't possess any stable isotopes. The known isotopes $^{86-115}\text{Tc}$ and $^{196-228}\text{Rn}$ are radioactive and undergo different decay processes. Nearly all technetium is produced synthetically, and only minute amounts are found in the Earth's crust. It is formed in larger amounts by neutron capture in stars. Naturally occurring technetium is a spontaneous fission product in uranium ore or the product of neutron capture in molybdenum ores. Radon is formed naturally in larger abundances in the radioactive decay chains through which ^{232}Th and $^{235,238}\text{U}$ slowly decay to stable $^{206,207,208}\text{Pb}$ isotopes.



Radon on Earth

Radon occurs everywhere where Uranium or Thorium exists! ^{220}Rn ($T_{1/2}=55\text{s}$) (Thoron) is the daughter isotope of ^{224}Ra in the ^{232}Th decay chain. ^{222}Rn ($T_{1/2}=3.82\text{d}$) is the daughter isotope of ^{226}Ra in the ^{238}U decay chain. All other Radon isotopes are negligible because of their short half life.

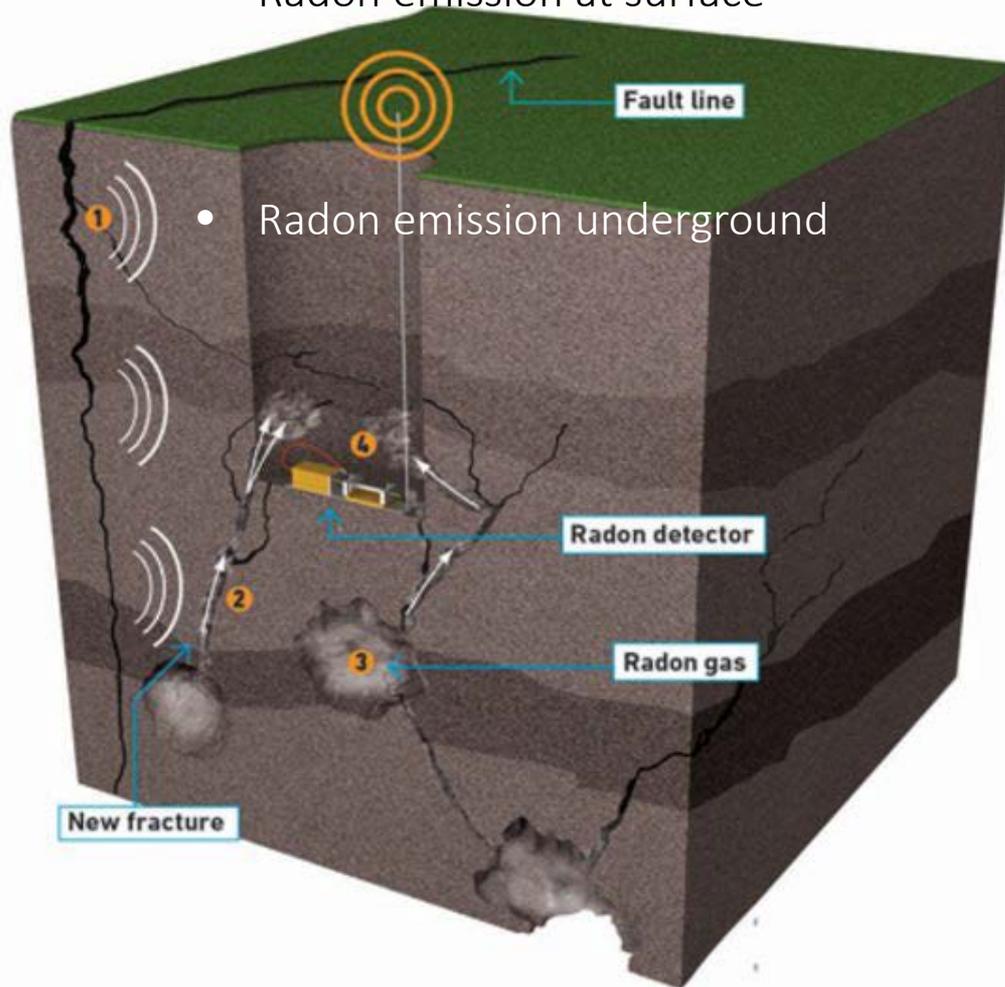


Radon diffuses out of the ground into the lower atmosphere. On average each square km of ground (with 15 cm depth) contains 1g Radium, emitting annually 16 mg of Radon into the atmosphere. The annual activity amounts to 91 TBq in α decay. The emission varies with environmental conditions from air pressure to earth quake. Hot springs near faults show distinct variations in Radon emission.

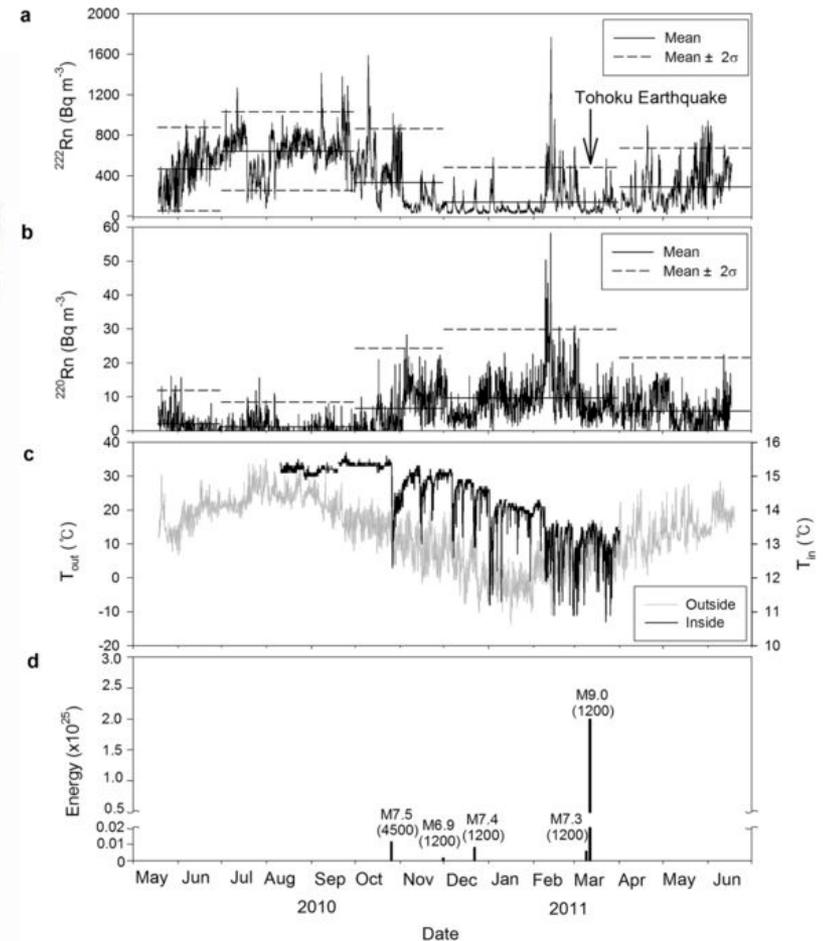
Radon Emission as Earth Quake Warning

Prediction methods

- Animal behavior
- Electromagnetic anomalies
- Radon emission at surface

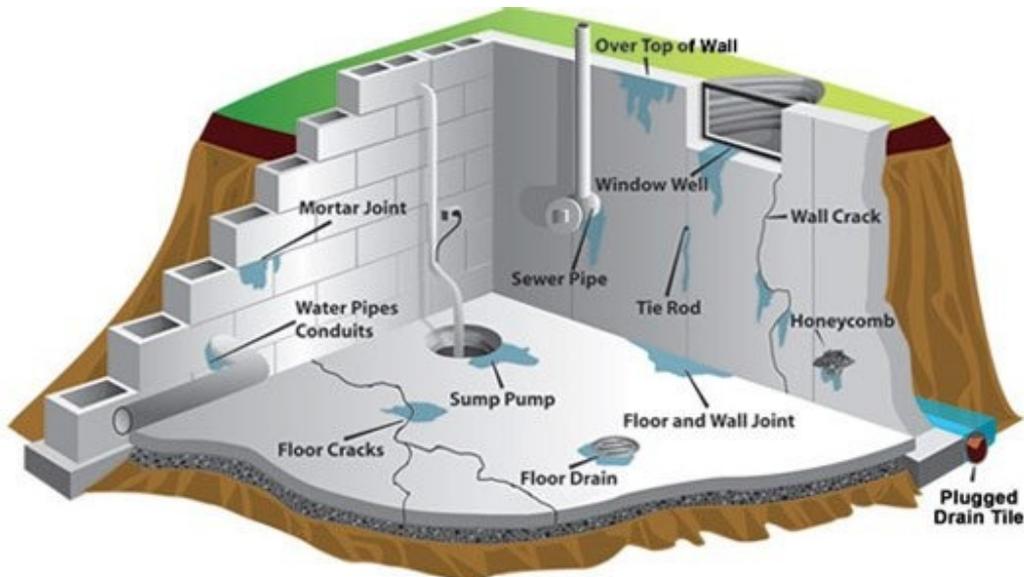


Seongryu Cave. In South Korea



(a) Hourly variations in ^{222}Rn activity. (b) Variations in 4-hour averaged ^{220}Rn activity. (c) Variations in air temperature during the monitoring period, both inside and outside the cave. (d) Energy (unit: $\text{erg} = 10^{-7}\text{J}$) of earthquakes with magnitudes greater than M6.0 in Japan and Malaysia during the monitoring period.

Impact on Human Dwellings



2.7 World Health Organization recommended **radon action level**.

4.0 The EPA recommended **radon action level**.



1 pCi/L of radon is equal to 2.5 cigarettes a day. The EPA states radon is the #2 cause of lung cancer - only smoking is #1.

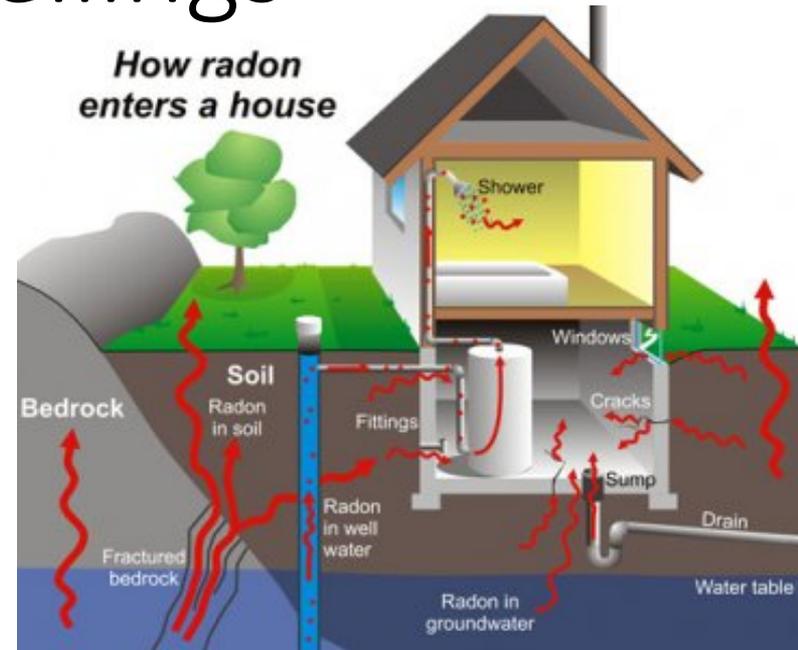
The amount of radiation in **4.0 pCi/L** of radon is equivalent to that in 100 chest X-rays. (Most hospitals only allow people to have 4 chest x-rays or .64 pCi/L each year.)

1 liter = 1000 cm³ = 0.001 m³

Density of air: **1.225 kg/m³** (0.001225 g/cm³),

Density of radon: **9.73 kg/m³** (0.00973 g/cm³),

Radon remains typically in basement environment!



Or it emits straight out of the wall material! It accumulates first in the basement, in particular when the basement is well insulated. It gets by diffusion into the upper layers of the house. During winter, heat circulation provided by the American Hot Air heating technic, provides a more efficient way for Radon to get up-stairs. An additional effect for further up-ward distribution is the stack or chimney effect.

Origin of Radon in Buildings

Source	Single-family homes (pCi/liter)	Apartments (pCi/liter)
Soil (estimates based on flux measurements)	1.5	< 1
Public water supplies	0.01 ^a	0.01 ^b
Building materials	0.05	0.1
Outdoor air	0.2	0.2

a From Nero (1985).

b Applies to 80% of the population that are served by public supplies. The contributions may average about 0.4 pCi/liter in homes using private wells, with higher concentrations in some areas.

The main source (85%) is the surrounding soil from which Radon manages to diffuse through building cracks into the basement, second source (11%) is coming from out-door air, where Radon is enriched through emanation from out-side soil and building materials. The third source 3% are building materials itself, the remaining 2% leak in from the public water supply system with water from aquifers and wells!



Radon Safety and Warning



Radon Reduction



Radon Testing



Free Estimate



From \$100 to \$1000



Radiation removal by soil depressurizing



From \$5 to \$50



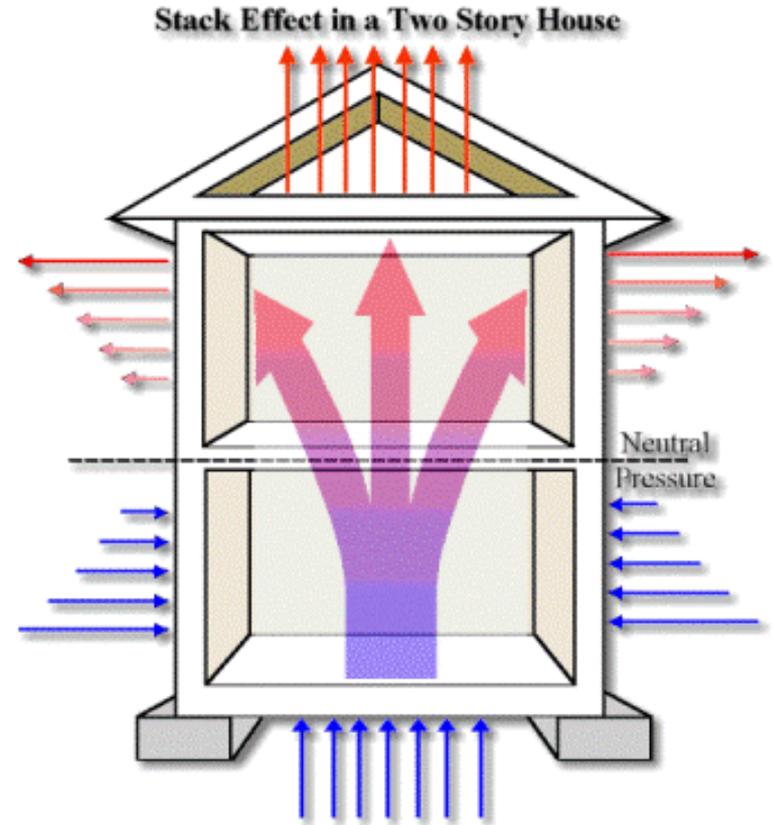
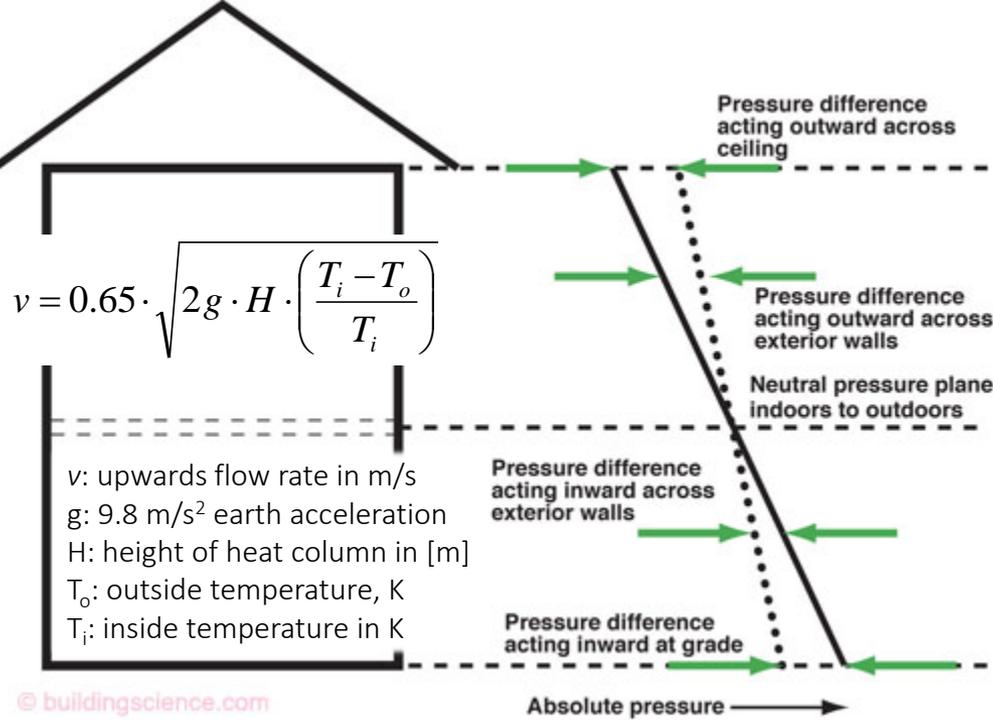
From \$1000 to \$10000



Radon removal from water supply system



The Stack Effect



The natural tendencies of air warmer than its environment is to rise upwards. If a basement of a two story home is heated, that heat is striving to reach the top floor, attic, and ultimately leave your home through the roof, soffit and attic venting. This reduces the air pressure in the basement, “sucking” more radon out of walls and cracks.

from house to high-rise:

H_H = 20 m H_{HR} = 200 m

Summer Winter

T_i ≈ 300 K T_i ≈ 300 K

T_o ≈ 310 K T_o ≈ 270 K

V_{H(Summer)} ≤ 0 m/s V_{H(Winter)} ≈ 4 m/s

V_{HR(Summer)} ≤ 0 m/s V_{HR(Winter)} ≈ 13 m/s

A new home in South Bend

Depending on temperature and ventilation conditions, the Radon activity is transferred into upper floors.



The Radon reading in the basement is 5 pCi/l

Inhalation

- Concentration of Radionuclide 1 in air = 10^5 Bq/m^3
- Breathing rate = $8,400 \text{ m}^3/\text{yr} = 2.7 \times 10^{-3} \text{ m}^3/\text{s}$
- Exposure duration = 2 hr = 7,200 s
- Intake = $1.9 \times 10^6 \text{ Bq}$
- DCF for inhalation = $1 \times 10^{-10} \text{ Sv/Bq}$
- Inhalation dose from Radionuclide 1 = $1.9 \times 10^{-4} \text{ Sv}$

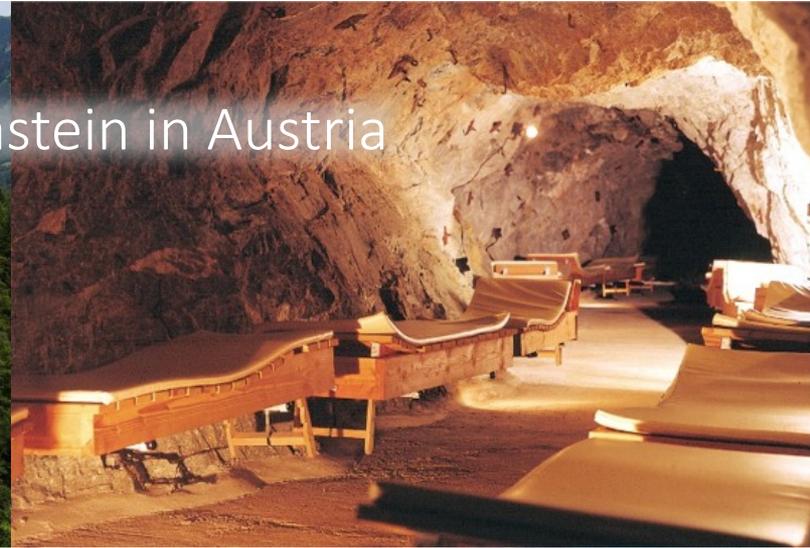
The Radon reading in the basement is 5 pCi/l air = 0.185 Bq/l. With 1 l = 0.001 m³ the Radon reading translates to Radon concentration of 185 Bq/m³.

Following the example above, the inhalation dose scales $3.6 \cdot 10^{-7} \text{ Sv}$ or 360 nSv after two hours of basement work. The exposure rate is 180 nSv/h or 0.18 $\mu\text{Sv/h}$. For short time this is 3.0 nSv/min or for basement apartment residents **1.6 mSv/y**. Cosmic ray exposure during flights is 2.5 $\mu\text{Sv/h}$. Chest X-ray **0.1 mSv**, human average is around **2.0 mSv/y**.

The Radon Spa Therapeutic Air and Waters



Bad Gastein in Austria



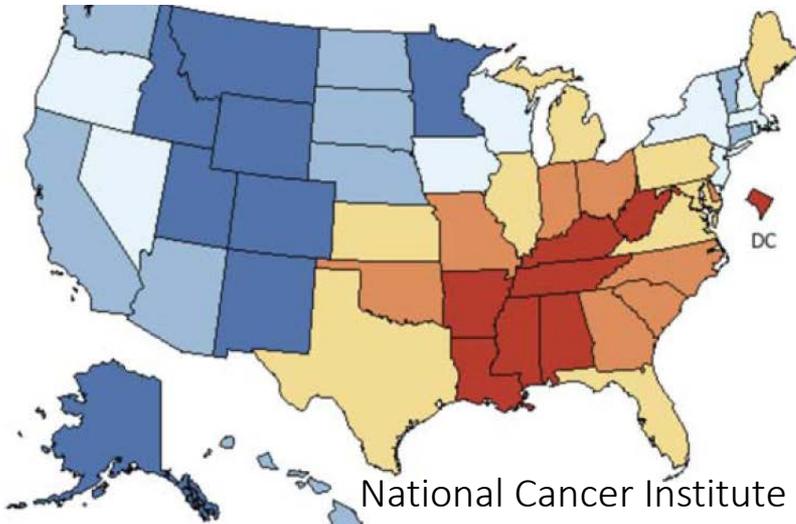
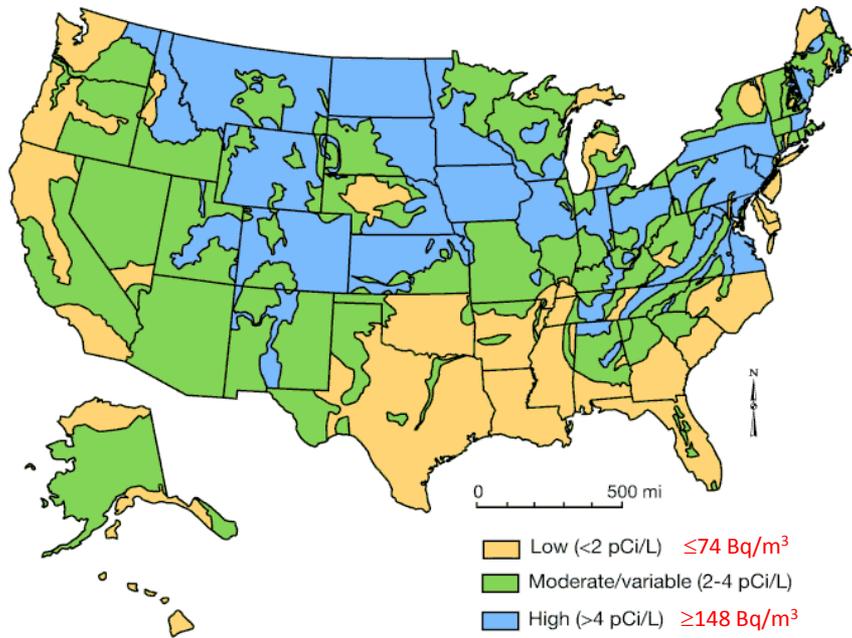
The Radon level in the treatment rooms is $170,000 \text{ Bq/m}^3$. This is a thousand time higher than present legal limits of 500 Bq/m^3 for homes.

The Radon activity concentration of $170,000 \text{ Bq/m}^3$ translates in a dose rate of $165 \mu\text{Sv/h}$. A week of spa experience with a 2 hour daily inhaling session provides the customer with a dose of 2.31 mSv or 0.23 Rem !

This is a third of the average natural annual total dose of 0.6 Rem ! No enhanced cancer rate has been detected in Bad Gastein Customers!

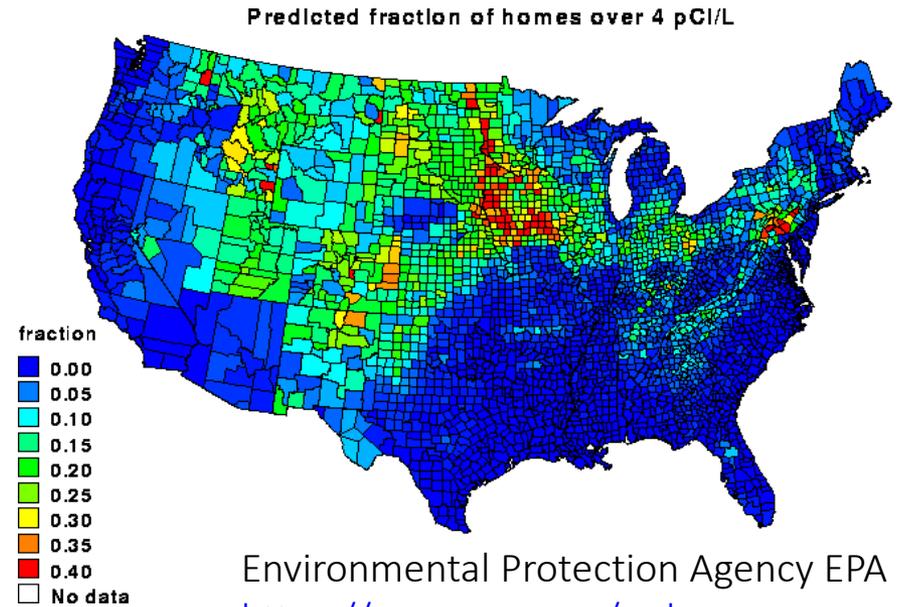


The Radon Distribution in the United States



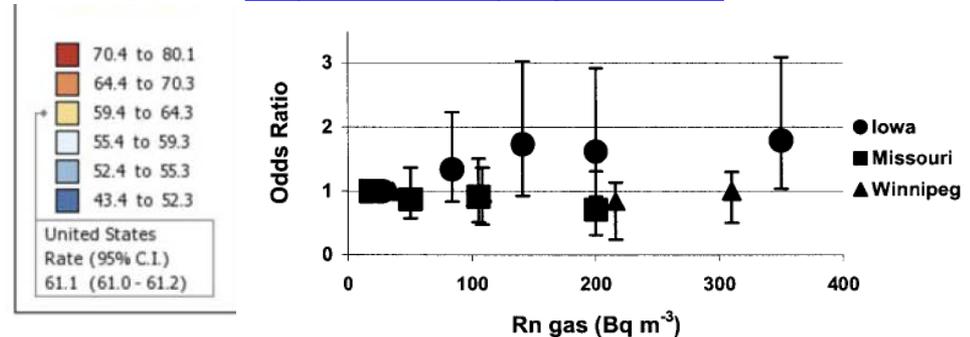
National Cancer Institute

<http://statecancerprofiles.cancer.gov/>



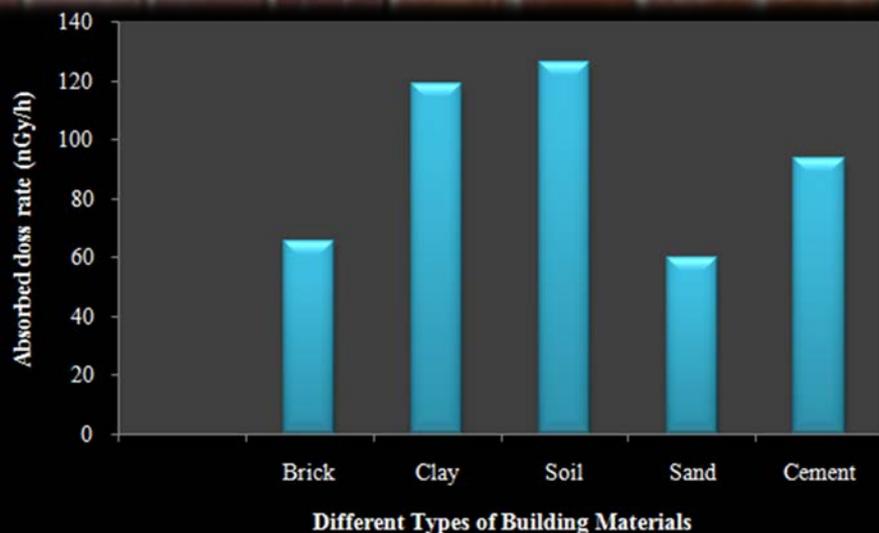
Environmental Protection Agency EPA

<https://www.epa.gov/radon>

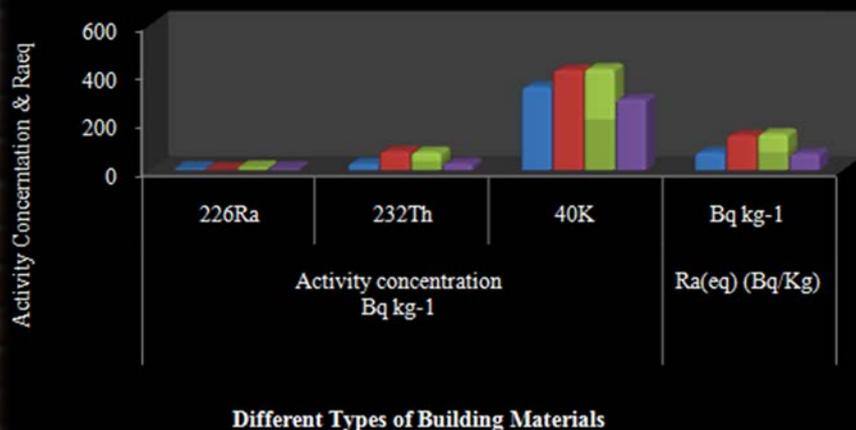


As pointed out in lecture 12, a meta risk analysis based on a number of international studies shows no statistical evidence for a radon lung-cancer correlation! This is confirmed by local oriented studies for Midwest states and various central European areas!

What are the other Sources of Home-made Radioactivity?



Radon emanation into the basement air generates a dose level of 100-200 nGy/h if inhaled, radiation level from the wall can be comparable (not to be confused with the Radon emanation from the wall) and reaches up to 120 nGy/h depending on the material composition. The radiation exposure is dominated by the 1.46 MeV γ -emission from ^{40}K in wall and floor material. A lesser component is the 2.6 MeV and other γ -radiation from the Ra-Th decay chain.



Natural Activity Levels of Building Materials

Source	Material	^{40}K	^{238}U	^{226}Ra	^{232}Th
			(radiation given in units pCi/kg)		
Chang et al. (1974) Taiwan	Wood	90	—	—	—
	Red Brick	16	1.2	—	1.8
	Concrete	7	0.9	—	—
Hamilton (1971) U. K.	Clay Brick	18	3	1.4	1.2
	Silicate Brick (Gravel)	10	0.2	0.2	0.1
	Granite	30	6	2.4	2.2
	Aerated Concrete	19	0.4	2.4	0.4
	Natural Gypsum	4	0.4	0.6	0.2
	Concrete Block (Fly Ash)	(6-16)	(1-12)	(0.2-4)	(1.0-1.2)
Wollenberg and Smith (1966a and b) U.S.	Cement	3.4	1.1	—	0.4
	Silica Sand	9	0.3	—	0.5
	Commercial Sand	7	0.3	—	0.3
Krisyuk et al. (1974) USSR	Red Brick	18	—	1.5	1.0
	Silica Brick	6	—	0.5	0.4
	Light Concrete	14	—	2.0	0.9
	Granite	40	—	3.0	4.5
	Sand	7	—	(<0.4-1)	<0.4
	Cement	4	—	0.7	<0.4
Kolb (1974) W. Germany	Granite	34	—	2.8	2.1
	Brick	18	—	1.7	1.8
	Sand, Gravel	<7	—	<0.4	<0.5
	Cement	6	—	0.7	<0.6
	Natural Gypsum	<2	—	<0.5	<0.3
	Concrete	7	—	0.6	0.6

1 pCi/kg = 37 mBq/kg \approx 56 Bq/m³ - 93 Bq/m³ with densities ranging from 1500 kg/m³ to 2500 kg/m³

Most of the released radiation given in is absorbed in the material, only decay processes from radioactive components located at the surface of bricks, glass or metals contribute.

Wood as Building Material

Plenty of wood in American houses and the ^{40}K content is significant 90 pCi/kg or 3.3 Bq/kg. The actual amount varies depending on the origin of the wood and the mineral content of the specific forest soil and can be considerably higher.

Taking the quoted value, a wood frame for a typical home weights 65 tons, the total ^{40}K activity is $2.15 \cdot 10^5$ Bq or 0.2165 MBq, which is rather negligible compared to other radioactivity sources.



Carbon is the main content of wood, this includes the radioactive ^{14}C . Assuming an average ratio of $^{14}\text{C}/^{12}\text{C} \approx 1.2 \cdot 10^{-12}$ means that 1 kg of wood contains about 94 Billion ^{14}C atoms. That corresponds to an average value of 0.36 Bq/kg. For a 65 ton house this translates into a ^{14}C -activity level of $2.34 \cdot 10^4$ Bq or 0.0234 MBq, a mere 10% of the ^{40}K based radiation level.

Other Building materials

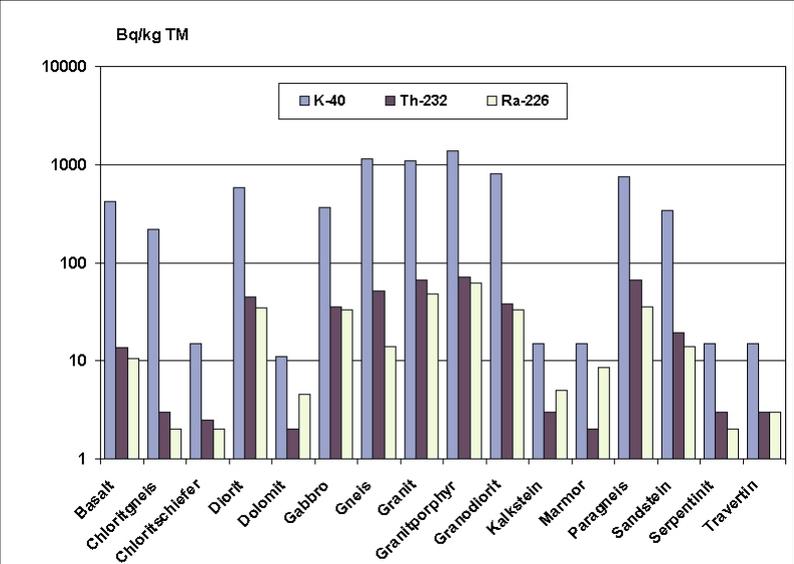
With higher considerable radioactivity content



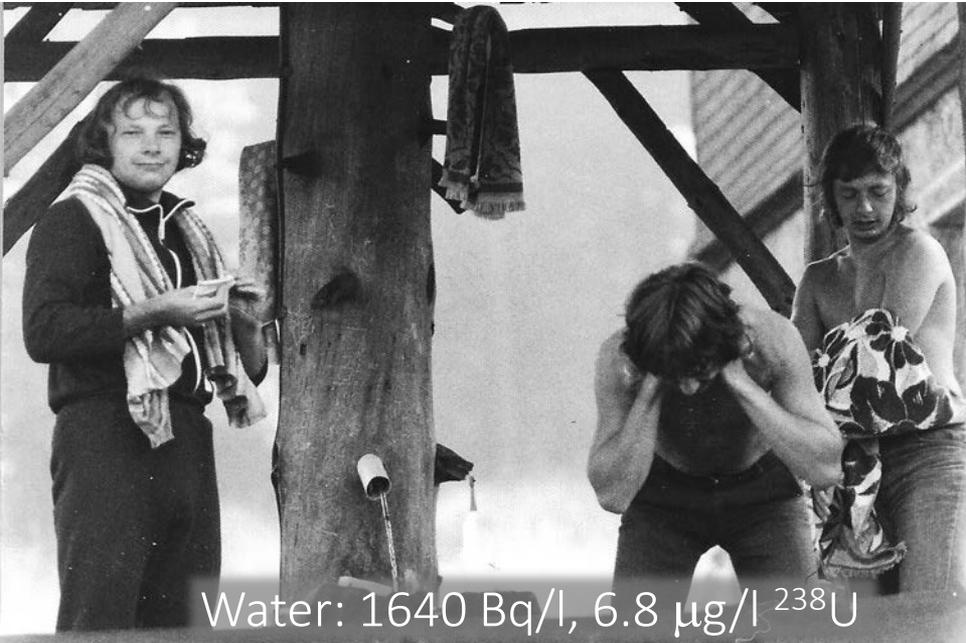
Estimates of Concentrations of Uranium, Thorium, and Potassium in Building Materials^a

Material	Uranium			Thorium			Potassium		
	ppm	mBq g ⁻¹	pCi g ⁻¹	ppm	mBq g ⁻¹	pCi g ⁻¹	%	mBq g ⁻¹	pCi g ⁻¹
Granite	4.7	63	1.7	2	8	0.22	4.0	1184	32.0
Sandstone	0.45	6	0.2	1.7	7	0.19	1.4	414	11.2
Cement	3.4	46	1.2	5.1	21	0.57	0.8	237	6.4
Limestone concrete	2.3	31	0.8	2.1	8.5	0.23	0.3	89	2.4
Sandstone concrete	0.8	11	0.3	2.1	8.5	0.23	1.3	385	10.4
Dry wallboard	1.0	14	0.4	3	12	0.32	0.3	89	2.4
By-product gypsum	13.7	186	5.0	16.1	66	1.78	0.02	5.9	0.2
Natural gypsum ^b	1.1	15	0.4	1.8	7.4	0.2	0.5	148	4
Wood ^b	—	—	—	—	—	—	11.3	3330	90
Clay brick ^c	8.2	111	3	10.8	44	1.2	2.3	666	18

Stone - Granite



Personal Reminiscences



Water: 1640 Bq/l, 6.8 $\mu\text{g/l}$ ^{238}U



Granite:
 ^{238}U : 170 Bq/kg
 ^{232}Th : 55 Bq/kg
 ^{40}K : 1200 Bq/kg
 Total: 1430 Bq/kg

Density of Water
 $\rho=1.0 \text{ g/cm}^3 \approx 1 \text{ kg/l}$
 Density of Granite
 $\rho=2.7 \text{ g/cm}^3 = 2700 \text{ kg/m}^3$
 Activity of Water
 1640 Bq/m^3
 Activity of Rock
 $3.86 \cdot 10^6 \text{ Bq/m}^3$



Dose absorbed ...

External Exposure

- Concentration of Radionuclide 1 on ground surface = 10^6 Bq/m^2
- Exposure duration = 10^5 s
- DCF = $1 \times 10^{-17} \text{ Sv/Bq s per m}^2$
- Dose from external exposure to Radionuclide 1 = $(10^6 \text{ Bq/m}^2) \times (10^5 \text{ s}) \times (1 \times 10^{-17} \text{ Sv/Bq s m}^{-2}) = 10^{-6} \text{ Sv}$

For one week fall break using $3.86 \cdot 10^6 \text{ Bq/m}^2$...

$$\text{Dose Rate: } 1.39 \cdot 10^{-7} \frac{\text{Sv}}{\text{h}} = 0.14 \frac{\mu\text{Sv}}{\text{h}} \quad 1 \text{ week} \equiv 6.05 \cdot 10^5 \text{ s}$$

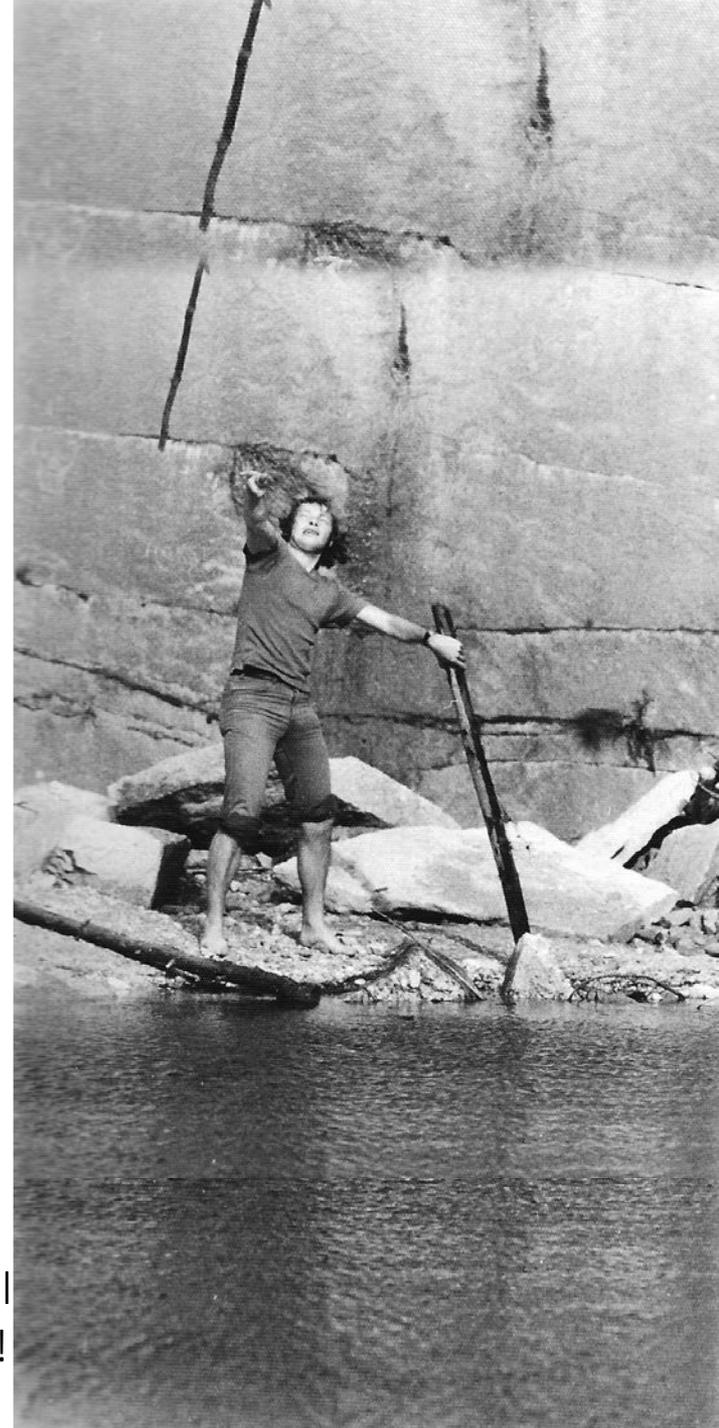
$$D = 3.86 \cdot 10^6 \frac{\text{Bq}}{\text{m}^2} \cdot 6.05 \cdot 10^5 \text{ s} \cdot 10^{-17} \frac{\text{Sv m}^2}{\text{Bq s}} = 2.33 \cdot 10^{-5} \text{ Sv}$$

$$D = 23.3 \mu\text{Sv} = 2.33 \text{ mRem}$$

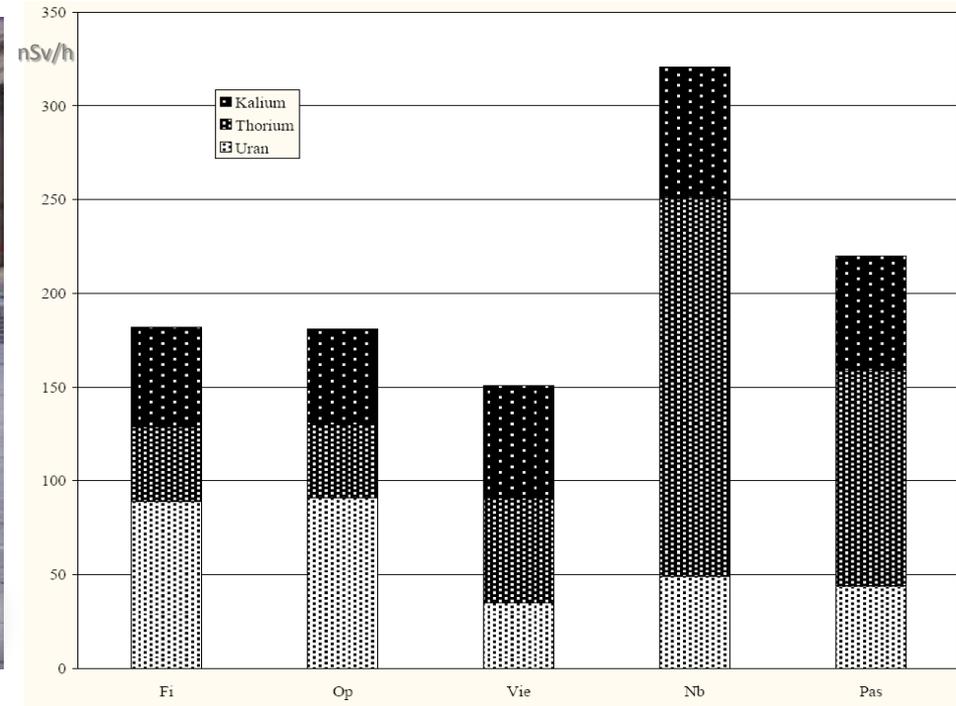
Average annual dose of human population is about 0.6 Rem with 3% from terrestrial soil is **18 mRem**.

That corresponds to an average weekly dose of **0.32 mRem**.

This translates in ten times the average human dose from soil activity, and an increase of 1% of the average natural activity!



Walking Granite tiled Streets



Actual exposure is with $\approx 0.3 \mu\text{Sv/h}$ (2.6 mSv/y) nearly a factor 2 higher than estimated before, because a higher activity granite was used.

The granite contains 19.5ppm uranium and 14.27ppm thorium and covers an area of $30,000 \text{ m}^2$ with a thickness of 10 cm This translates to 8100 Tonnen Granit including 158 kg uranium and 119 kg thorium.

Walking on soil (0.56 Bq/m^2) gives you an average dose of $0.02 \mu\text{Sv/h}$ (0.17 mSv/y)

Legal limits for commercial areas 6 mSv/y for residential

Radioactive Houses

Bayreuth, Germany



Radiation exposure through enhanced Radon emission from clay filling materials of walls reaching values of 300 Bq/m^3 (compared to 185 Bq/m^3 for South Bend homes) and through radioactivity level of granite foundations. With 100 m^2 of granite (0.5 m wall thickness) and 360 m^3 of space volume the activity level is about 0.11 MBq (Radon) + 19.3 MBq (wall), a total of about 19.5 MBq is reached. This yields an exposure of 292 nSv/h from Radon and 140 nSv/h from walls reaching about 420 nSv/h or 3.8 mSv/y above the average value 3.1 mSv/y for all natural exposure.

Ramsar, Iran



Ramsar is the location with the highest natural activity level world-wide with up to 260 mSv/y , 42 times higher than the average population exposure of 6.2 mSv/y . The building materials are therefore highly radioactive as well, depending from which of the local quarries they come from. The picture shows a reading of 142 mSv/y near the wall of the building. This is nearly forty times higher than the German granite building. Despite the fact that Ramsar is populated since ancient times, no enhanced cancer occurrence is observed or reported.

American Homes



Radon content: 100 Bq/m³
Wall activity from gypsum: 3830 Bq/m²:

Radon dose: 97 nSv/h
Wall dose: 0.14 nSv/h
Total dose: 97 nSv/h
Corresponds to 14% of the total
human average dose of 6.2 mSv/y.



Radon content: 185 Bq/m³
Wall activity from brick: $1.64 \cdot 10^5$ Bq/m²:

Radon dose: 180 nSv/h
Wall dose: 5.9 nSv/h
Total dose: 186 nSv/h
Corresponds to 26% of the total
human average dose of 6.2 mSv/y.