RADON IN GROUNDWATER

2023 INDOOR AIR SYMPOSIUM
Nashville TN

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Research papers at Researchgate.net

History of Federal Radon in Water Standard

1974 SDWA enacted : EPA regulates drinking water quality

1986 EPA directed to establish radon in water standard

1991 EPA proposes radon in water MCL of 300 pCi/L :
lifetime risk → 2/10,000

1999 EPA proposes allowing radon up to 4000 pCi/L in water

- IF state or water system developed
- multimedia mitigation (MMM) program

NO FEDERAL RULE EVER IMPLEMENTED

Exposures from radon in drinking water supply:

Inhale radon gas

- Radon is released into air when water is used.
- Inhalation of radon increases the risk of lung cancer.

Activity = $\lambda * N$

- 4 pCi = 9 dpm = 71,000 radon atoms (3.5×10^{-14} g)

Drink the water

- Stomach cells could be exposed to increased radiation.

168 cancer deaths/year (USA): 89% lung 11% stomach

Radon adds <20 stomach cancers/year to the 26,000

National Research Council (US), Committee on Risk Assessment of Exposure to Radon in Drinking Water, 1999..

Is my drinking water at risk for radon?

Radon is soluble in water.

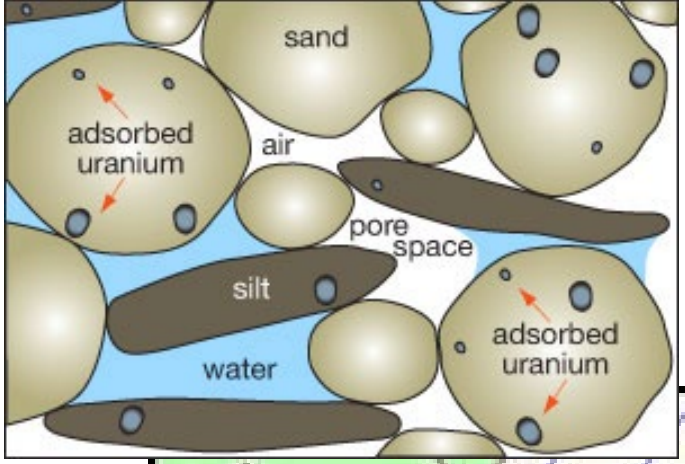
Radon dissolves into water as it passes over rocks and through soil.

Ground waters:
(10 – 1,000,000 pCi/L)
(may be seasonal variation)

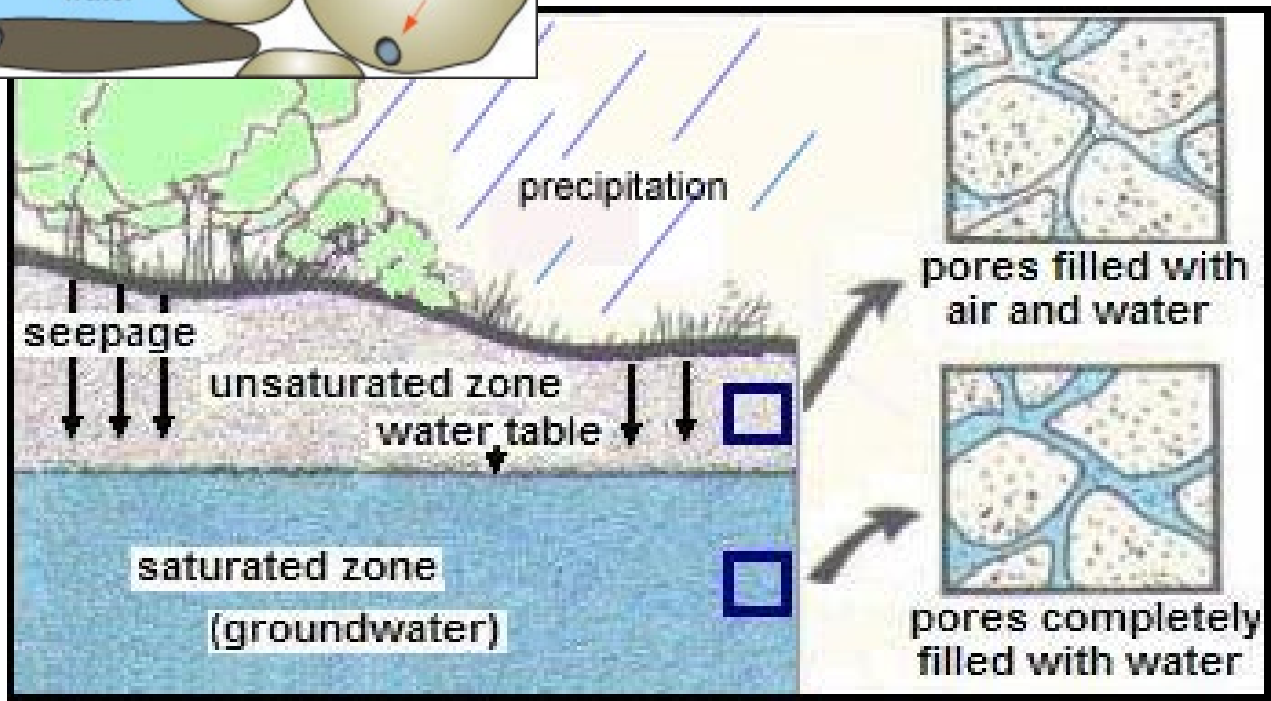
Surface waters:
contain low levels (<100 pCi/L)

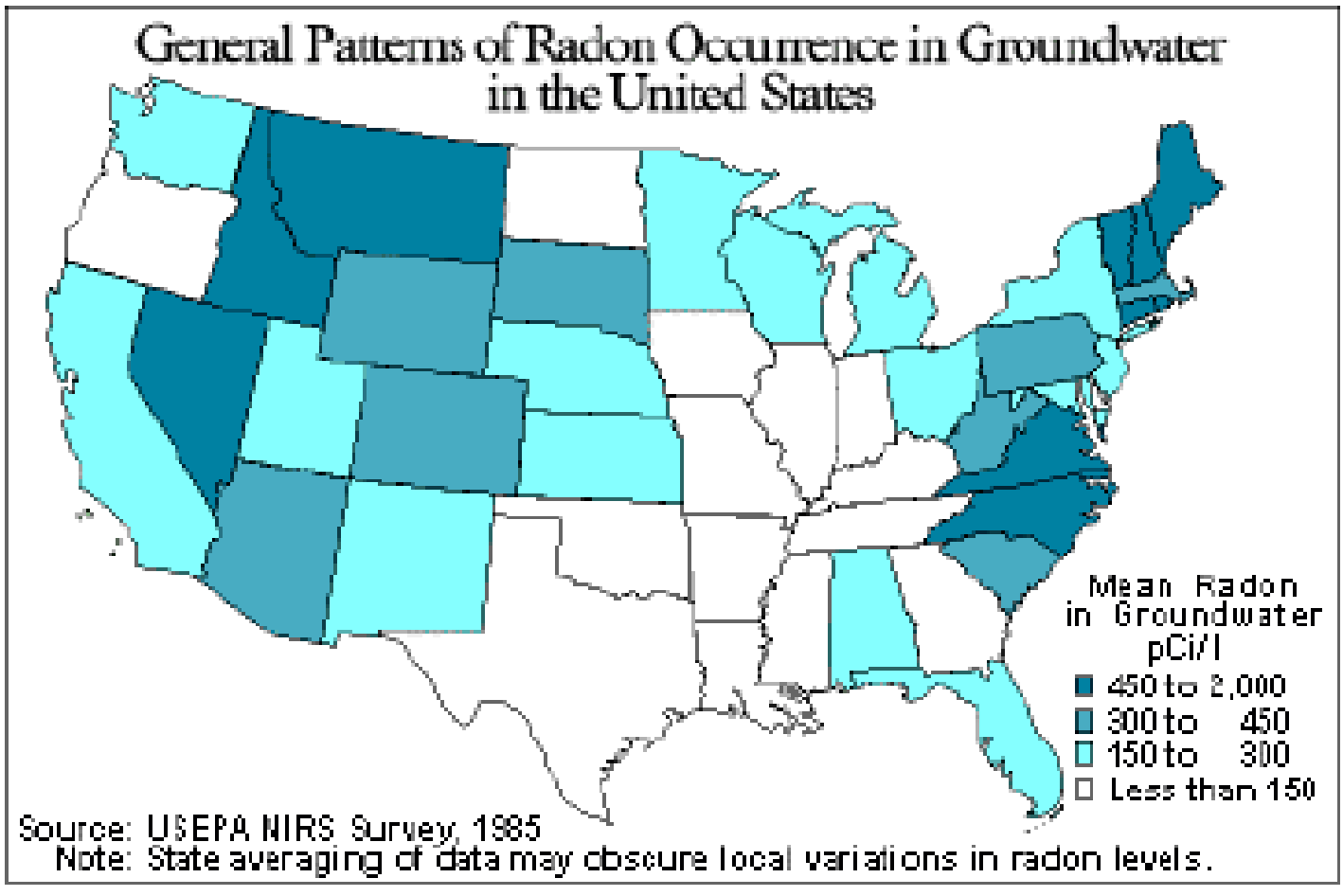
Radon level in water <u>decreases</u> when

- water is agitated (treatment, distribution, usage)
- water is stored (holding tank, reservoir)

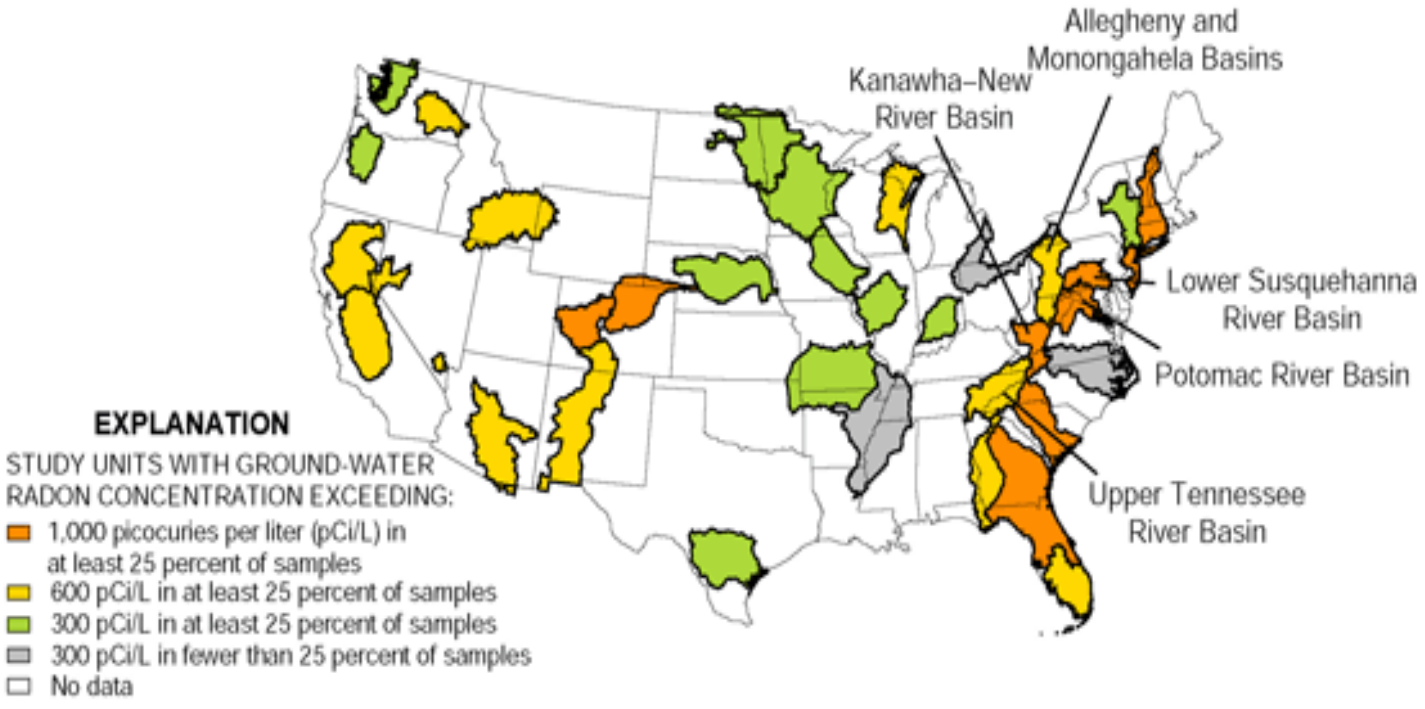


Adsorption of radioactivity onto particle surface depends on water chemistry





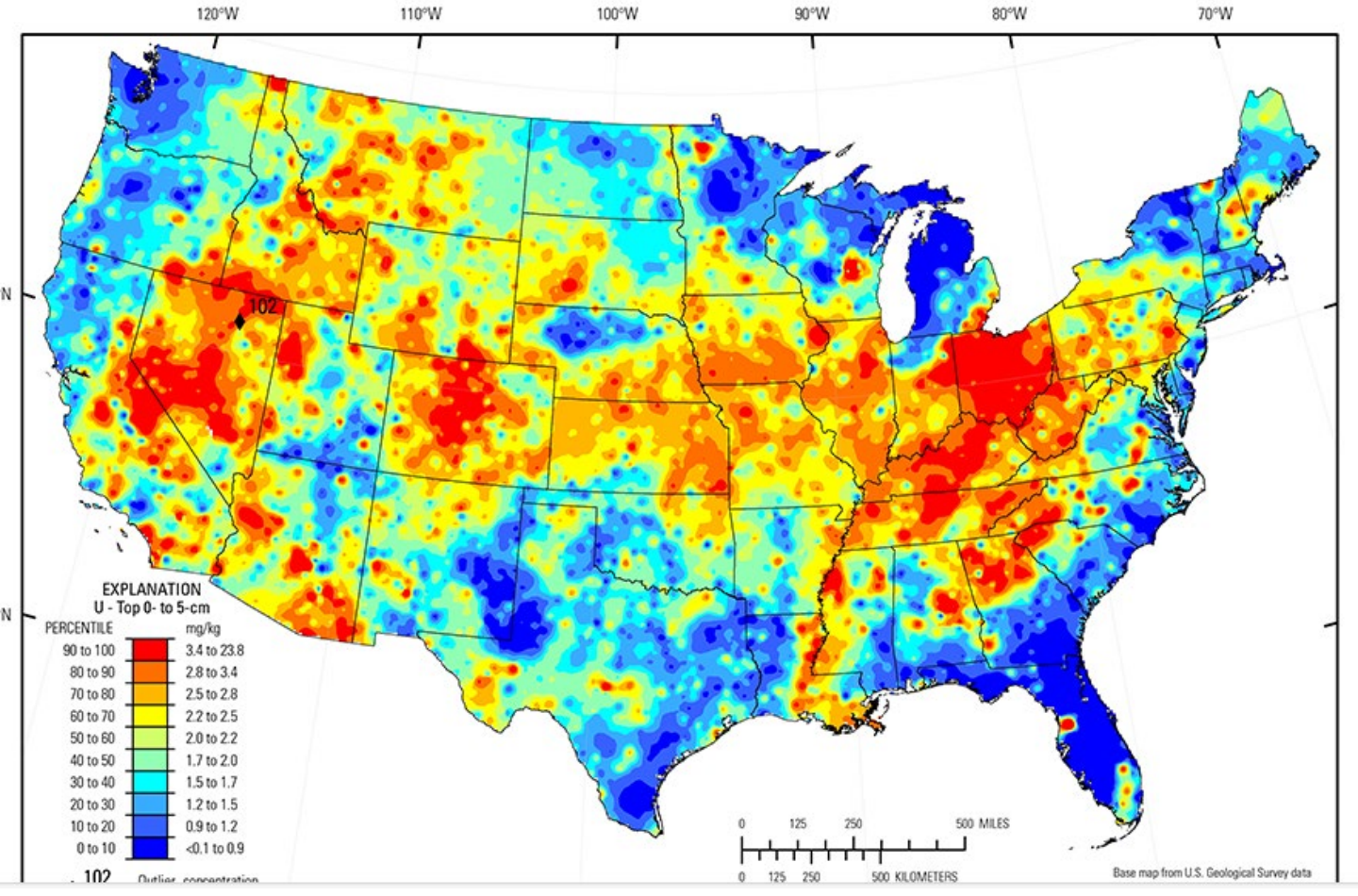
New England Appalachian Rocky Mountain parts of Southwest and Great Plains



Bedrock geological units vary greatly in radionuclide (U, Ra, etc).

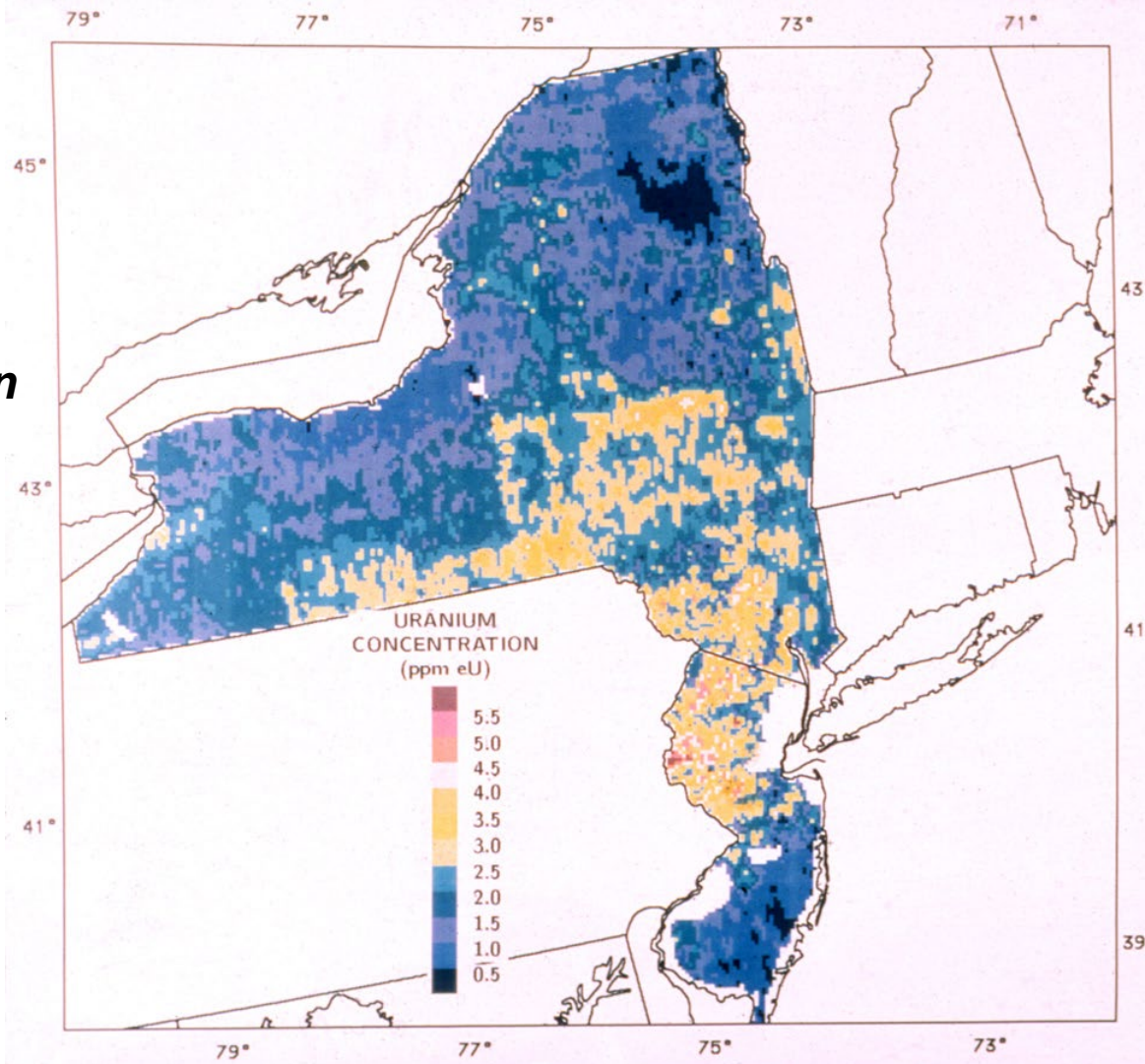
Hornblende gneiss has been identified as geology likely to contain U and Ra in groundwater.

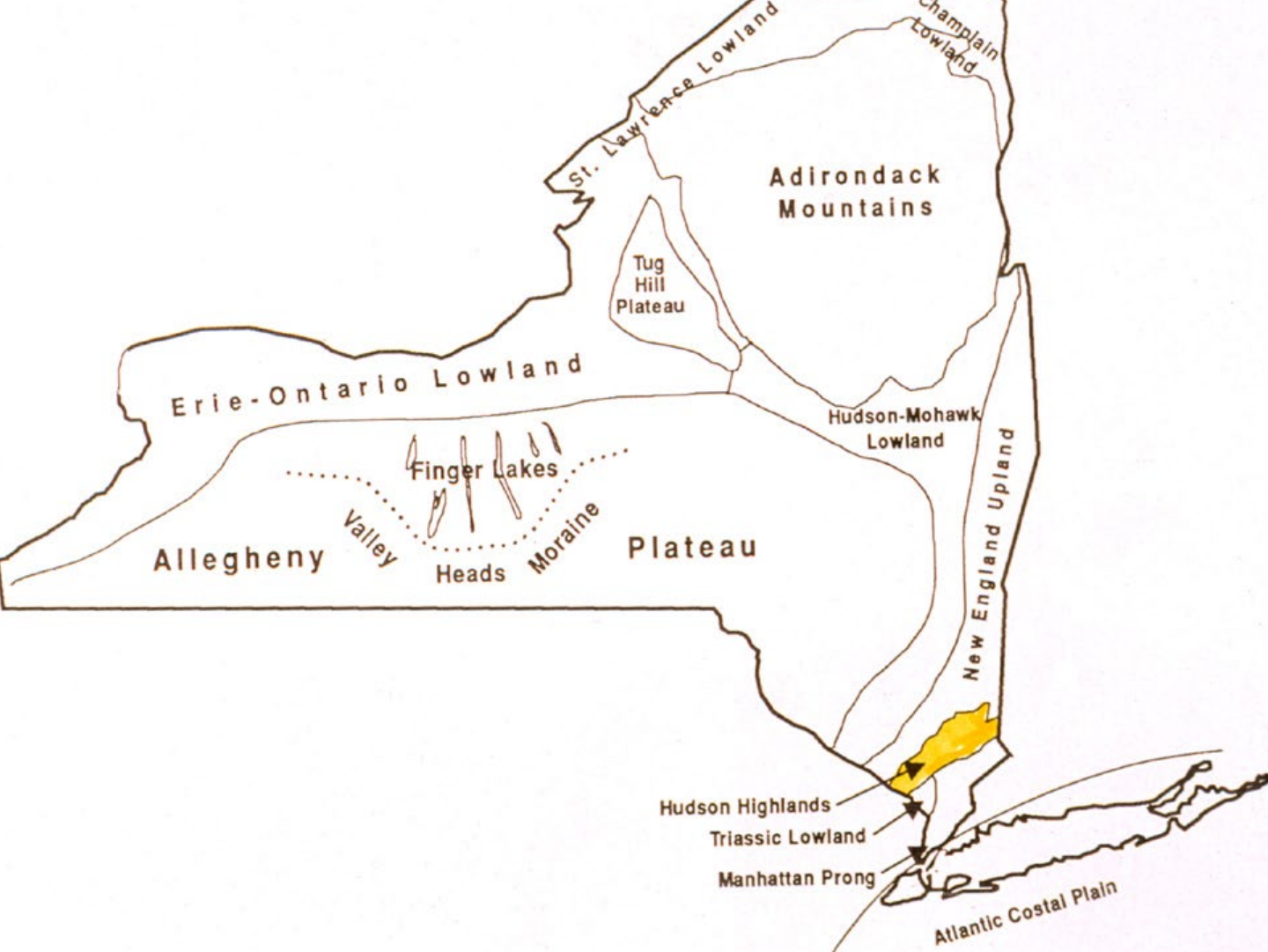
Uranium


120°W
110°W
100°W
90°W
80°W
70°W
102
EXPLANATION
U - Top 0- to 5-cm
PERCENTILE
mg/kg
90 to 100
3.4 to 23.8
80 to 90
2.8 to 3.4
70 to 80
2.5 to 2.8
60 to 70
2.2 to 2.5
50 to 60
2.0 to 2.2
40 to 50
1.7 to 2.0
30 to 40
1.5 to 1.7
20 to 30
1.2 to 1.5
10 to 20
0.9 to 1.2
0 to 10
<0.1 to 0.9
102
Outlier, concentration
0 125 250 500 MILES
0 125 250 500 KILOMETERS
Base map from U.S. Geological Survey data

NURE

National Uranium Resource Evaluation




St. Lawrence Lowland
Champlain Lowland
Adirondack Mountains
Tug Hill Plateau
Erie-Ontario Lowland
Hudson-Mohawk Lowland
New England Upland
Finger Lakes
Valley Heads Moraine
Allegheny Plateau
Hudson Highlands
Triassic Lowland
Manhattan Prong
Atlantic Costal Plain

Orange County

bedrock geology

Ask your
state
geologis

Miles

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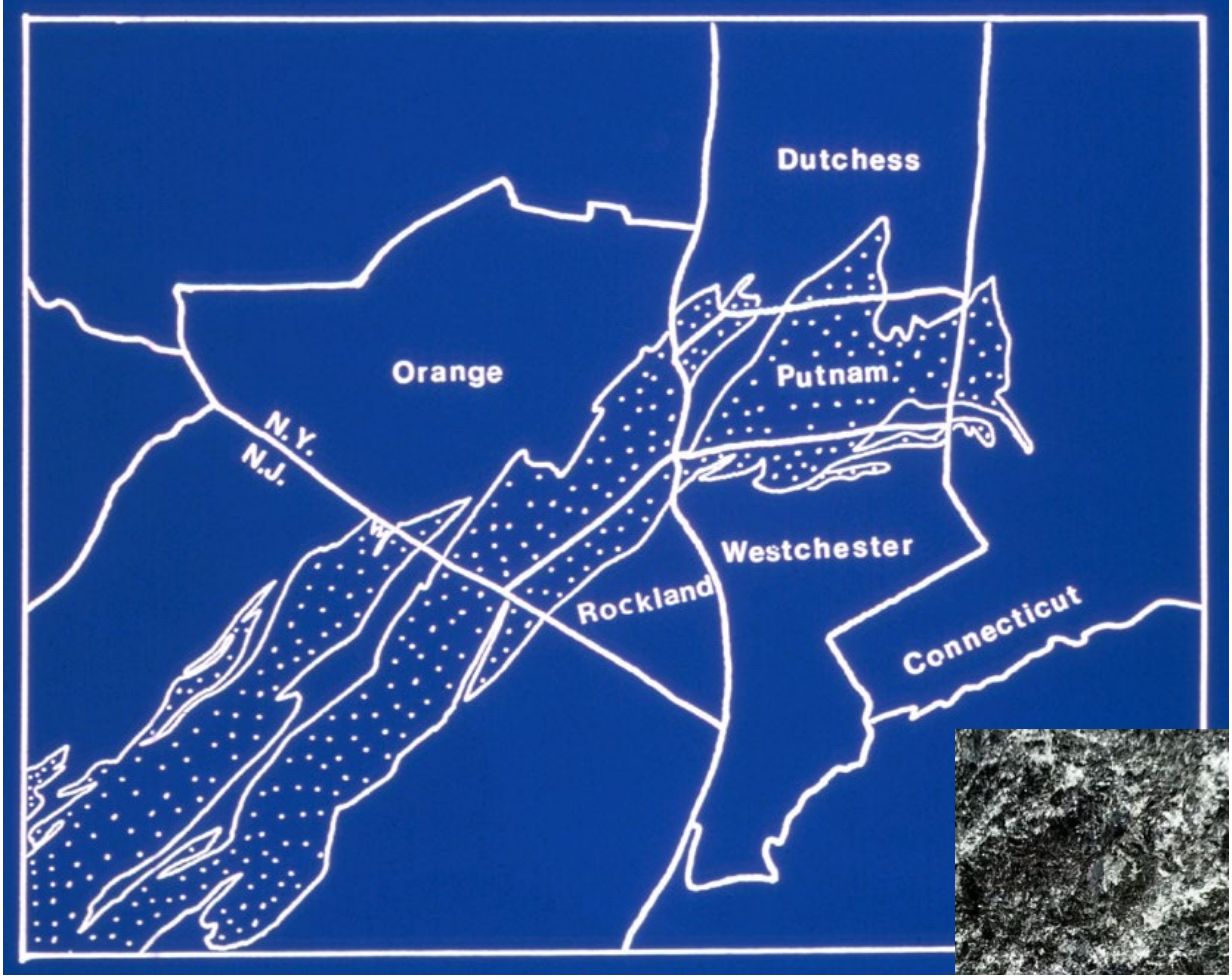
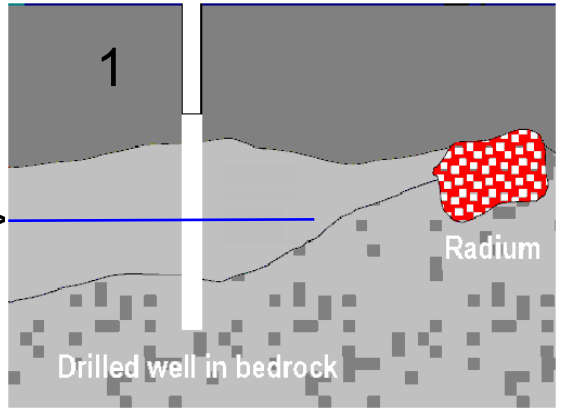


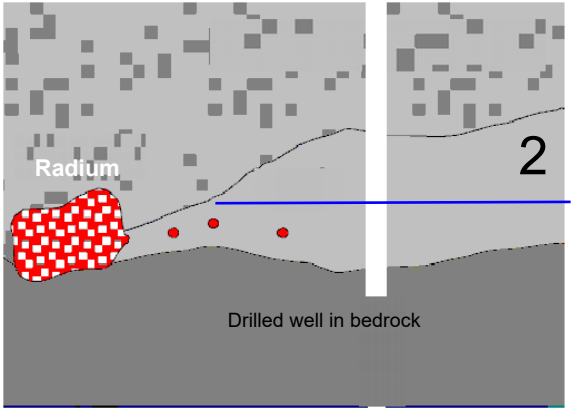
Examine bedrock geology maps.

Horneblende gneiss

Contact time is function of use:
Low water table and high use may minimize water contact with radium

low water table; > little input from radium deposit





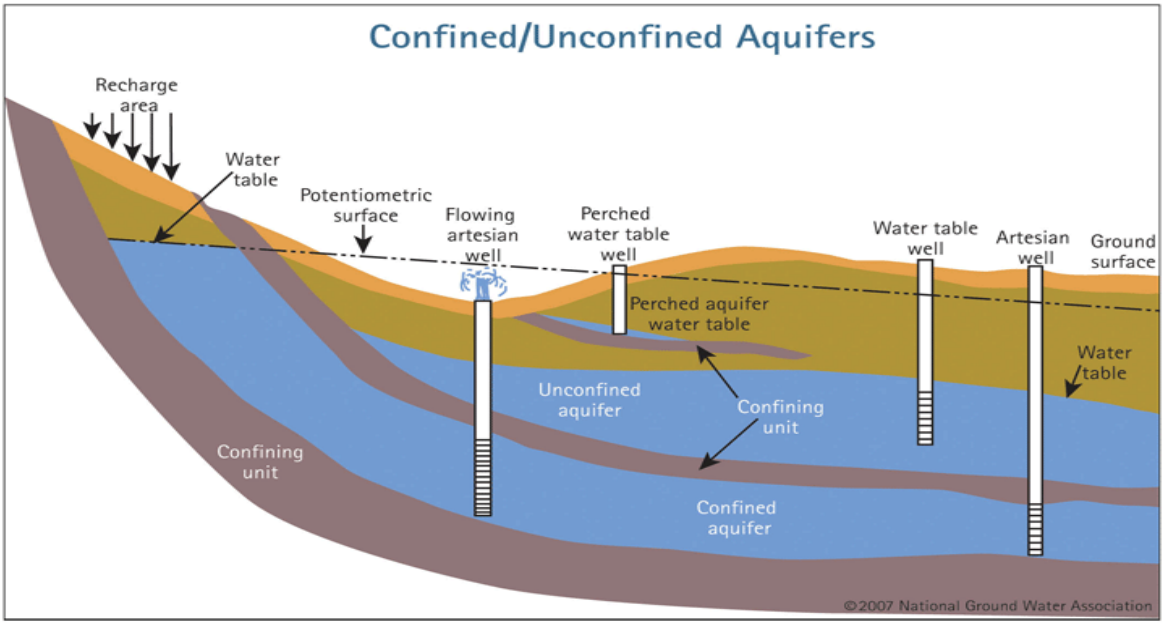
< low water table; large input from radium deposit

Seasonal variations due to varied contributions from water veins

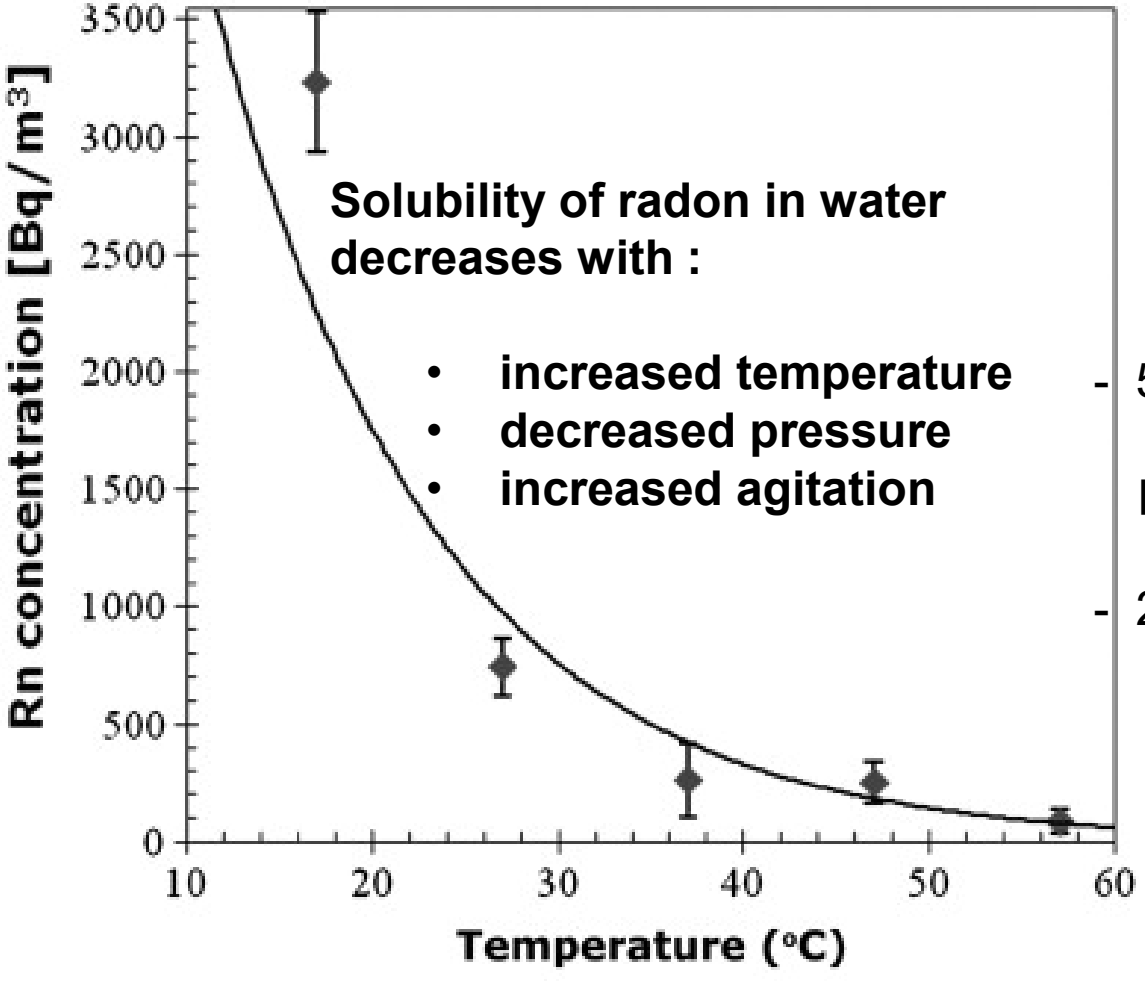
About 16 million water wells exist in the U.S.
(~0.5 million new residential wells are constructed annually)

44% of US population use groundwater for drinking water

13 million homes have own well



Consolidated (small volume) vs. Unconsolidated aquifers (PWS)


Rn concentration [Bq/m3]
3500
3000
2500
2000
1500
1000
500
0
10
20
30
40
50
60
Temperature (°C)
Solubility of radon in water decreases with :
• increased temperature
• decreased pressure
• increased agitation

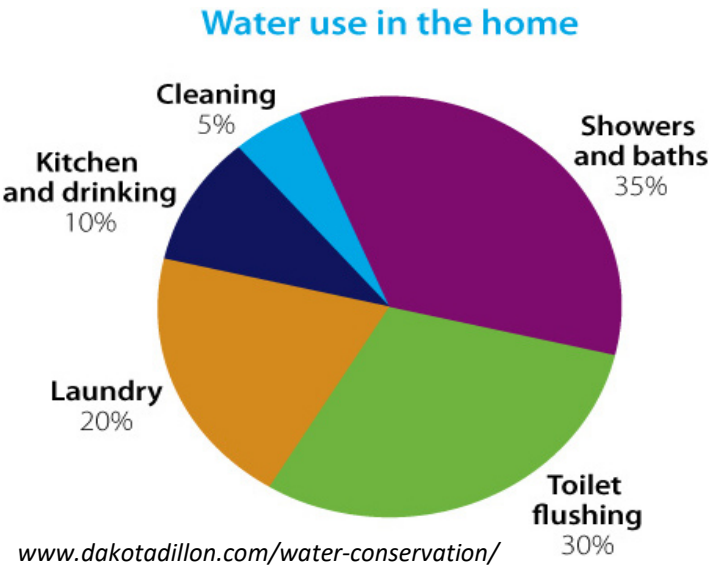
- 54 pCi/L - 27

General 10000-to-1 rule of thumb

Example: 4,000 pCi/L in water → 0.4 pCi/L in air (outdoor level)

Factors affecting contribution from water to air

1. Solubility of radon in water
2. Type of water-use activity
3. Amount of water used in building
4. Volume of building
5. Ventilation rate of building



www.dakotadillon.com/water-conservation/

Transfer Efficiency

Environ. Sci. Technol. **1997**, *31*, 1822–1829

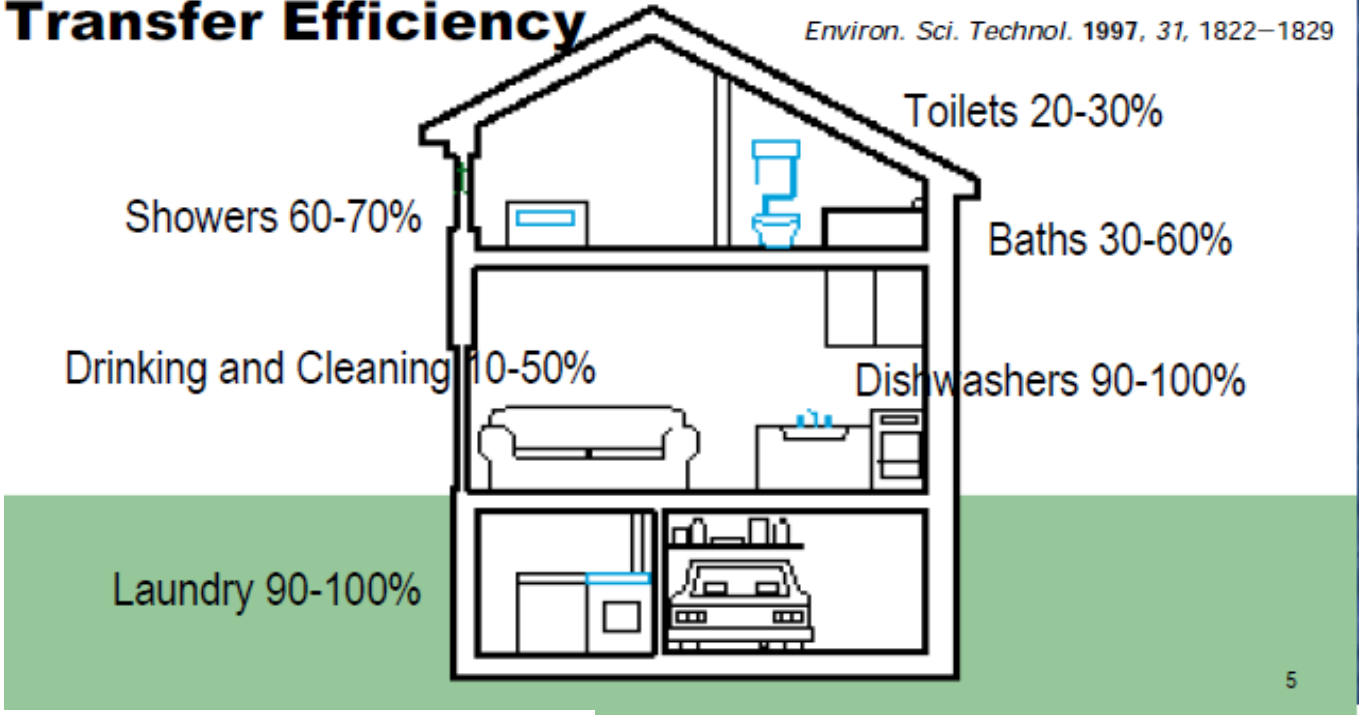


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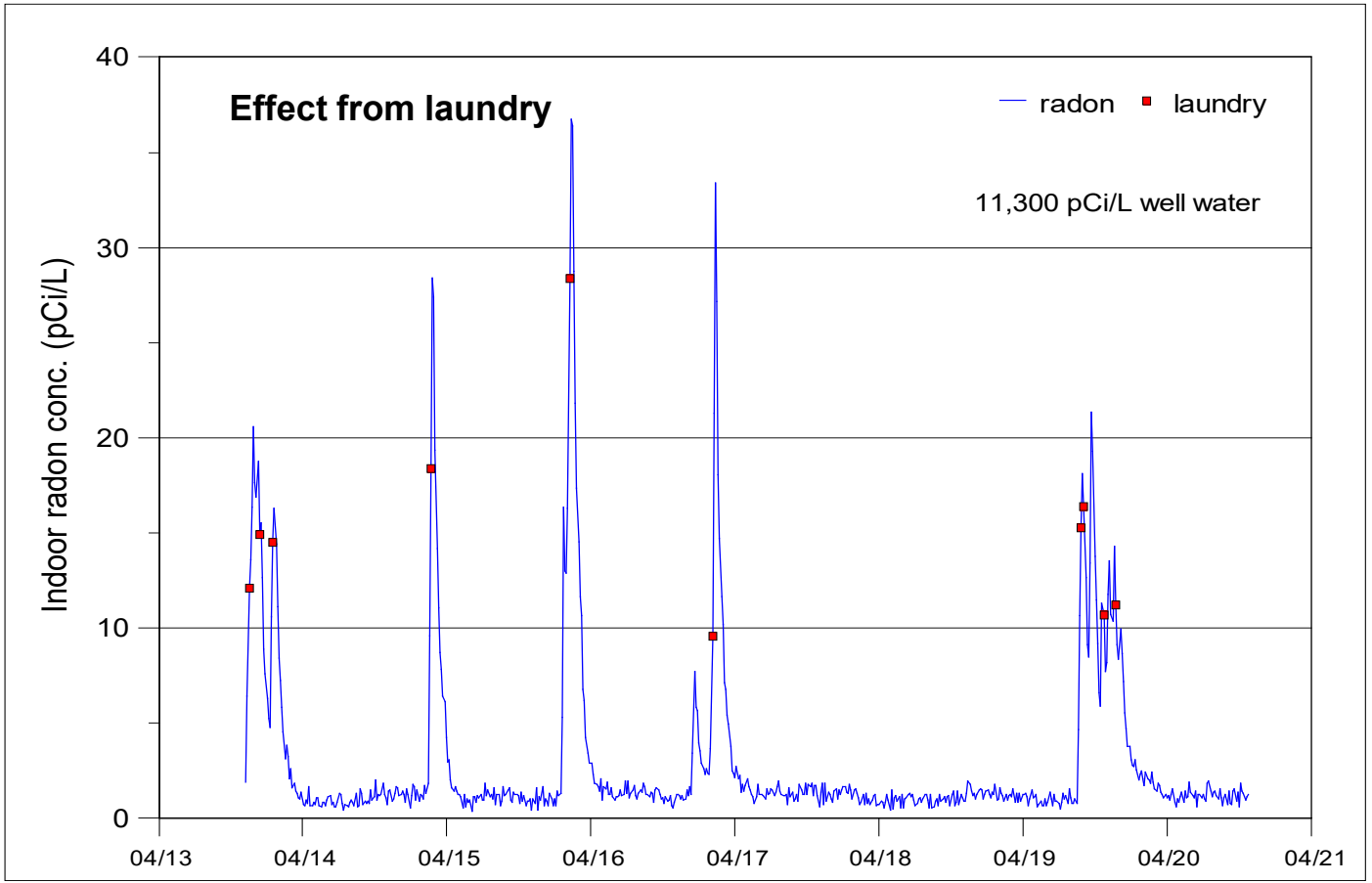
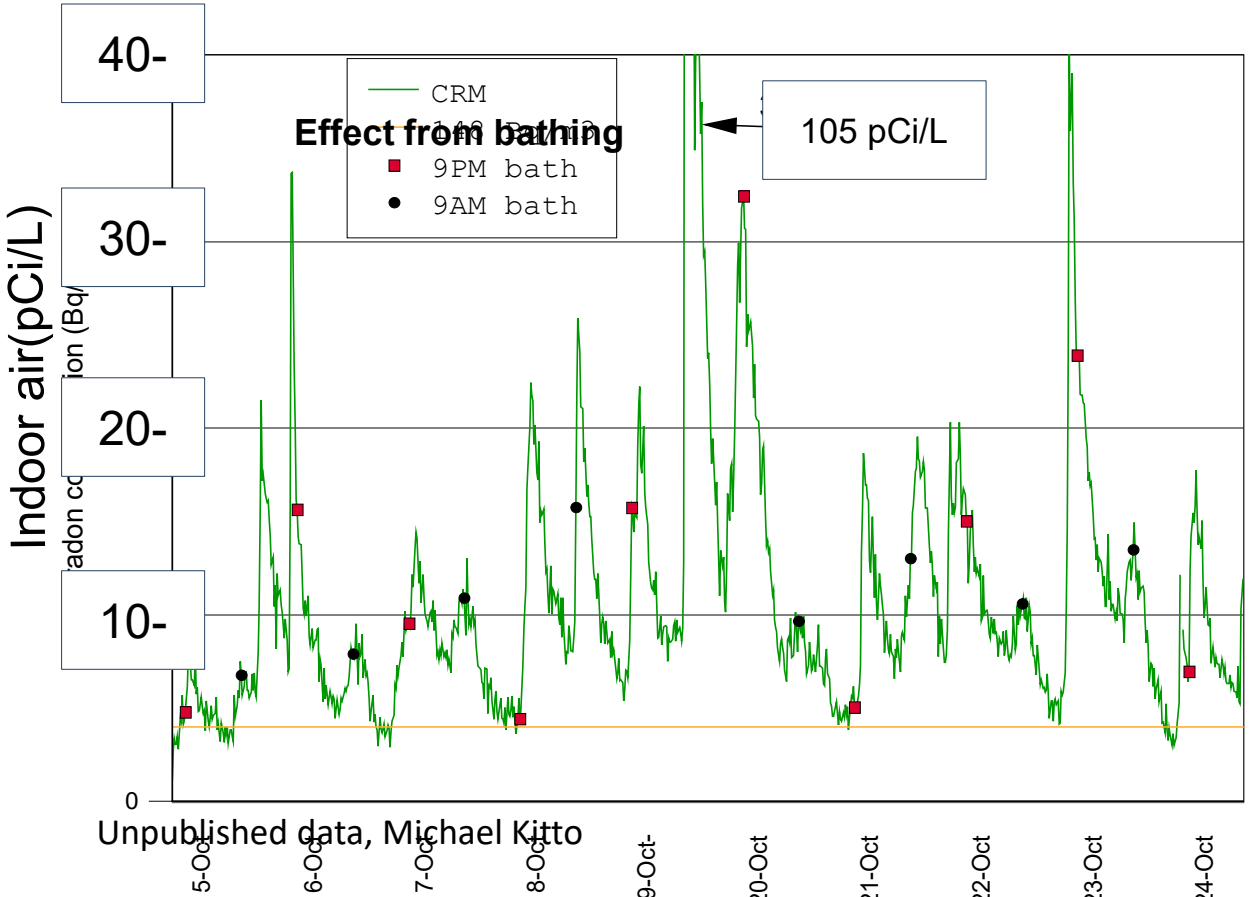
TABLE 1. Laboratory Measured Emanation Fraction

shower head	water temp (°C)	^{222}Rn in water concn before shower (kBq m^{-3})	^{222}Rn in water concn after shower (kBq m^{-3})	emanation[a] (%)
head 1	32	374	108	71
	32	773	233	70
	21	375	124	67
	21	207	58	72
head 2	32	254	69	73

Typical water use :
75 gallons per person per day

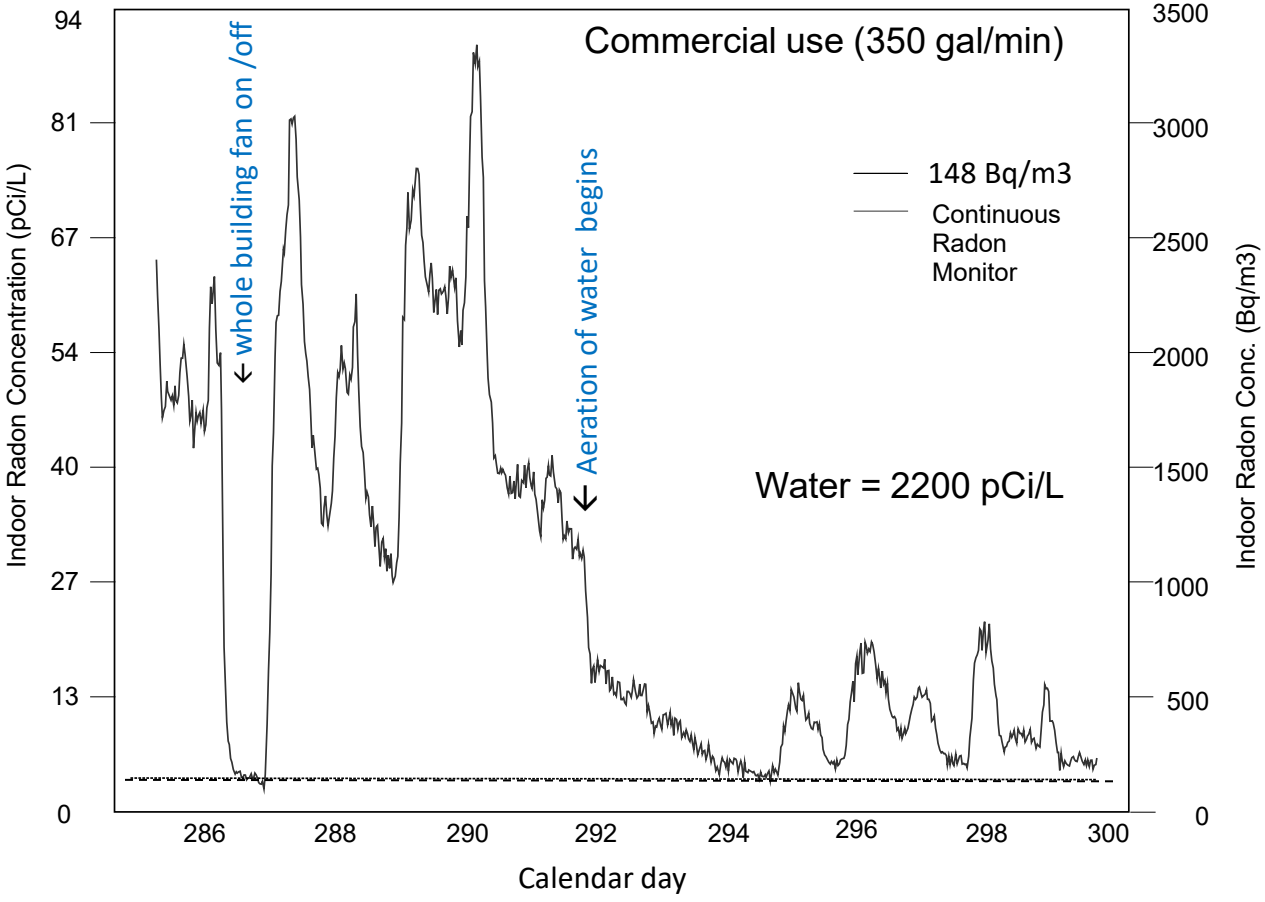


Unpublished data, Michael Kitto



Unpublished data, Michael Kitto

Hatchery



Health Phys. 74(4), 451-455 (1998)

Existing/planned maximum contaminant levels (MCLs) for radon in water

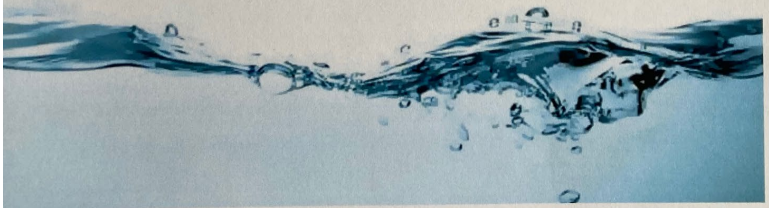
State	Recommended MCL (pCi/L)
Massachusetts	10,000
Wisconsin	5,000
Connecticut	5,000
Vermont	5,000
Maine	4,000
Rhode Island	4,000
New Hampshire	2,000
New Jersey	800

ANSI/AARST **MW-RN 2020**

An Approved American National Standard

Protocols for the Collection, Transfer and Measurement of Radon in Water

AARST CONSORTIUM ON NATIONAL RADON STANDARDS



Recommendations for sampling of radon in water

Collect sample as near to well head as possible (prior to treatment, storage, etc.)
This may be accomplished by sampling from an outside tap

Purge sufficiently long to get fresh sample. Consider the following :

- length of water line
- depth of well
- diameter of water line
- water flow rate
- presence and size of pressure tank

Typical home water flow from an outside spigot is 3-5 gallons per minute.

Recommendations for sampling of radon in water

Run the water long to get fresh sample

Example: For a “fresh” water sample

- 2.5 cm diameter piping
- 76 m depth to well water
- 14 m of piping through home

dispose of at least 50 liters of water

Remove faucet aerator

Collect prior to treatment or holding tank

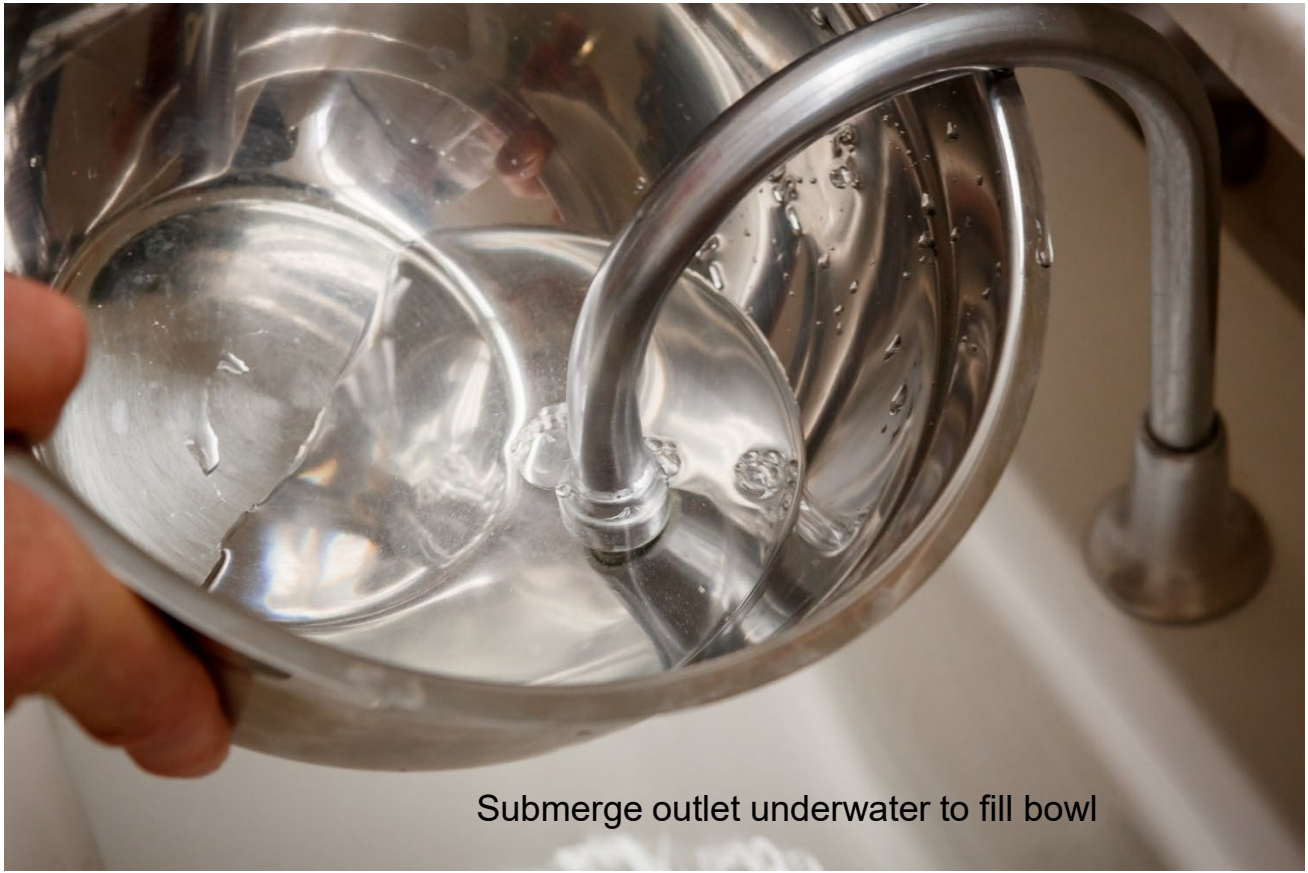
If using collection bottle, supplies needed include :

glass bottles only

Teflon or aluminum lined cap (retards radon release)

taller rather than wider bottles (less surface area)

Submerged faucet and funnel


Submerge outlet underwater to fill bowl

Open bottle underwater


Slow flow.
Tubing at bottom of bottle.
Fill bottle and cap.


Inspect water sample for bubbles

Inject water under scintillation fluid

Fill syringe from bottom of bowl of water

Fill syringe from bottom of funnel

Water slowly overflows funnel


Slide bottle under faucet is NOT acceptable

Analytical methods for measurement of radon in water

- Liquid Scintillation counting
- Alpha Scintillation ("Lucas") cell
- Electret
- Continuous Radon Monitor (Rad-7; Pylon)
- Isotopic Gamma Spectrometry

Laboratories demonstrate measurement proficiency

NOTE : Radon level in water sample does NOT equate to Ra-226 level.

Rn-222 and Ra-226 are not in equilibrium in fresh water sample.

To obtain Ra-226 concentration, wait 40 days and measure radon

SUMMARY OF ANALYTICAL METHODS

Liquid scintillation:

- Direct injection of the water below scintillation fluid in a glass vial
- Inherently **easy, rapid**, and in common usage
- Detection limit commonly about **20 pCi/L**
- Potentially hazardous scintillation **fluid to discard**

Lucas cell:

- Radon bubbled (de-emanated) from the water sample
- Radon swept into an evacuated ZnS coated airtight cylinder
- **Time consuming**
- Detection limit **below 1 pCi/L**
- **No disposal problem**

Gamma :

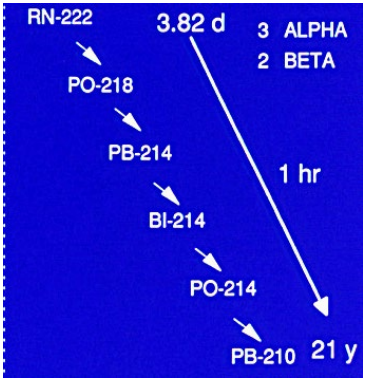
- Fill large standardized counting container (>0.5 L)
- Fill by submerging spigot under the surface of the water
- Slow-flowing water to overflow the container for 2 minutes
- Cap, assuring that no air is trapped in the container

- Electret:
- Inherently easy; 24 hr for results
- Somewhat expensive (> $2000)
- Good detection limit
- No scintillation fluid to discard

CRM flow through :

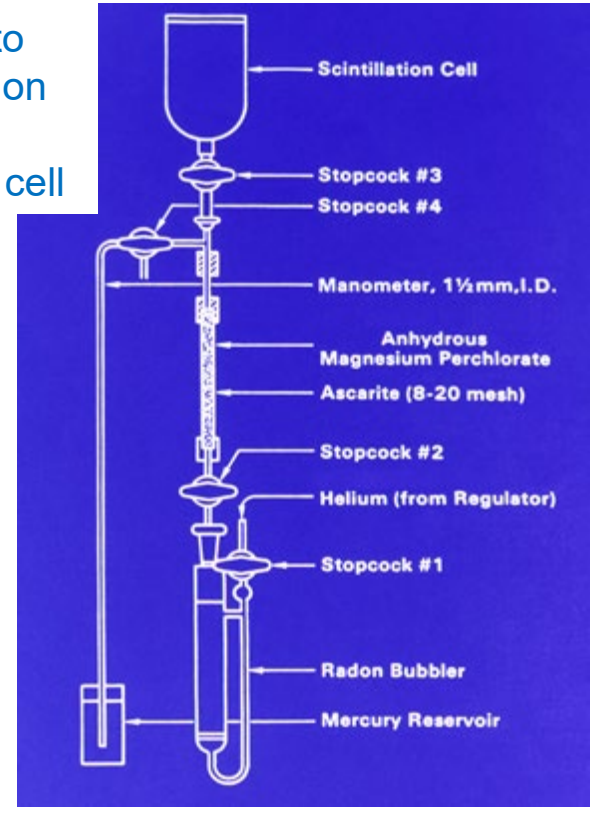
Expensive initial investment (>$7000)
Good detection limit
No scintillation fluid to discard

Liquid scintillation counter can measure a series of radon cocktails.



5 cpm / dpm

Apparatus to transfer radon into alpha scintillation cell



Stand alone Lucas cell counter

Computer controlled counters for alpha scintillation cells

Measurement using electret method

Kitto, J. Environ. Radioact. 99, 1255-1257 (2008)

Continuous Radon Monitors

with water attachment

Gamma-ray spectroscopy

RADON IN WATER INTERCOMPARISONS CONDUCTED BY KITTO

2009 participants:

USA Gov't lab	1
State lab	4
County lab	1
Private company	12
Private individual co.	2
University	3

2010 participants:

15 states and 1 international

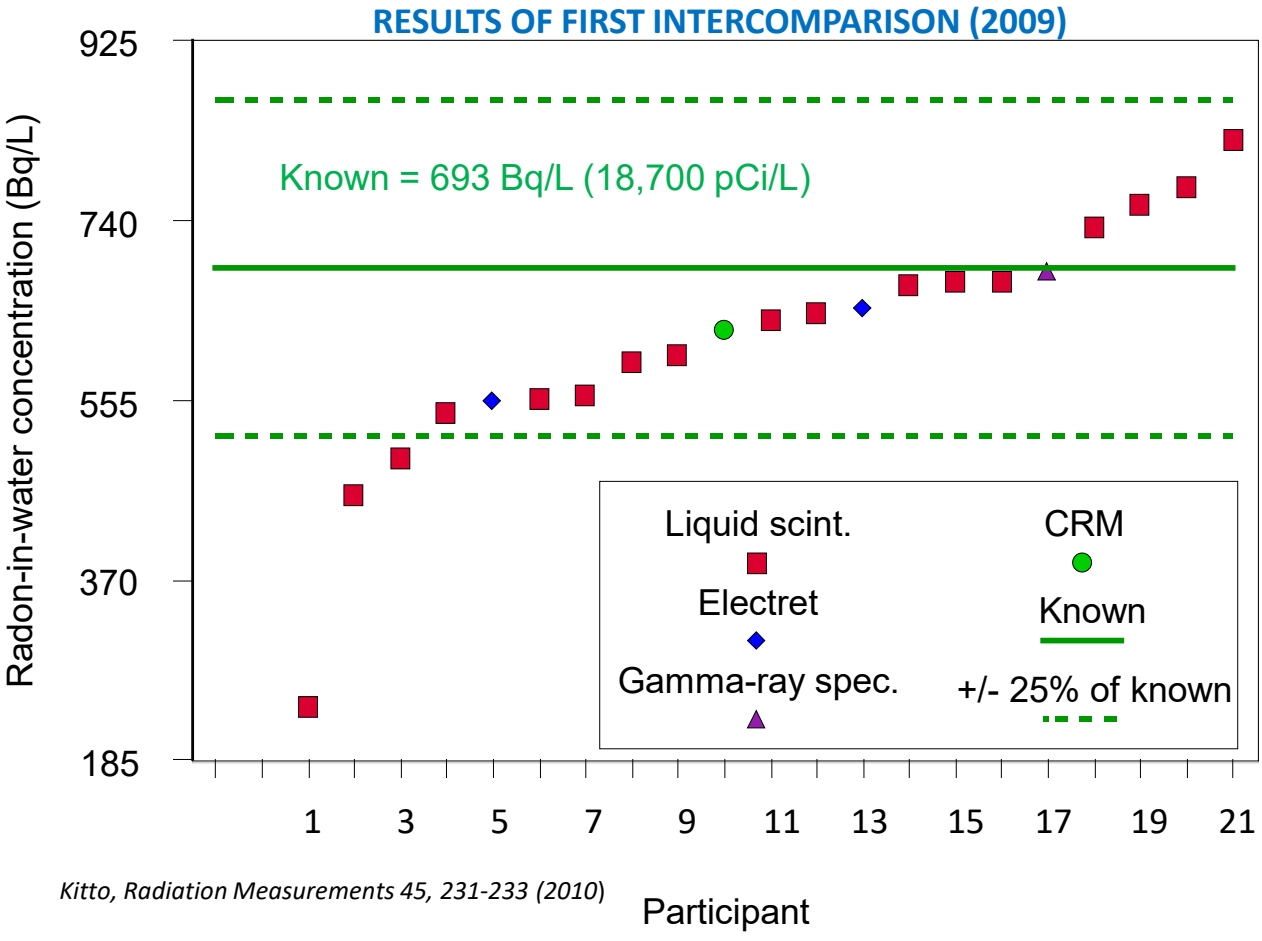
CA	NC
CO	NH
CT	NJ
FL	NY
IA	PA
LA	SC
MA	WI
MD	non-USA

2016 study

Bulgaria	1
Canada	1
Finland	1
Estonia	1
France	2
Germany	1
Italy	10
Moldova	1
Montenegro	1
Poland	1
Portugal	2
Serbia	1
Spain	1
Sweden	1
USA	13

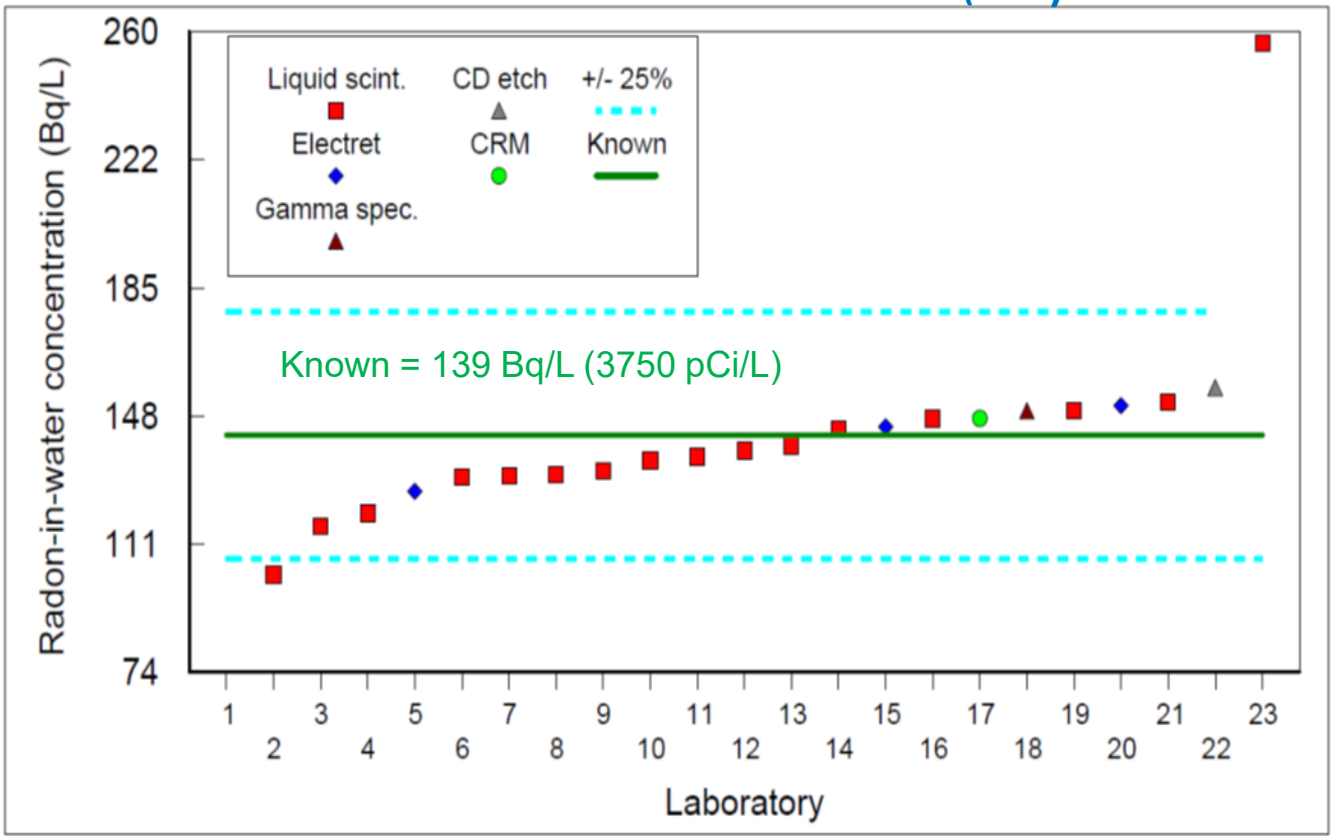
Reusable source
for radon in water

Radiation Measurements 45, 231-233 (2010)



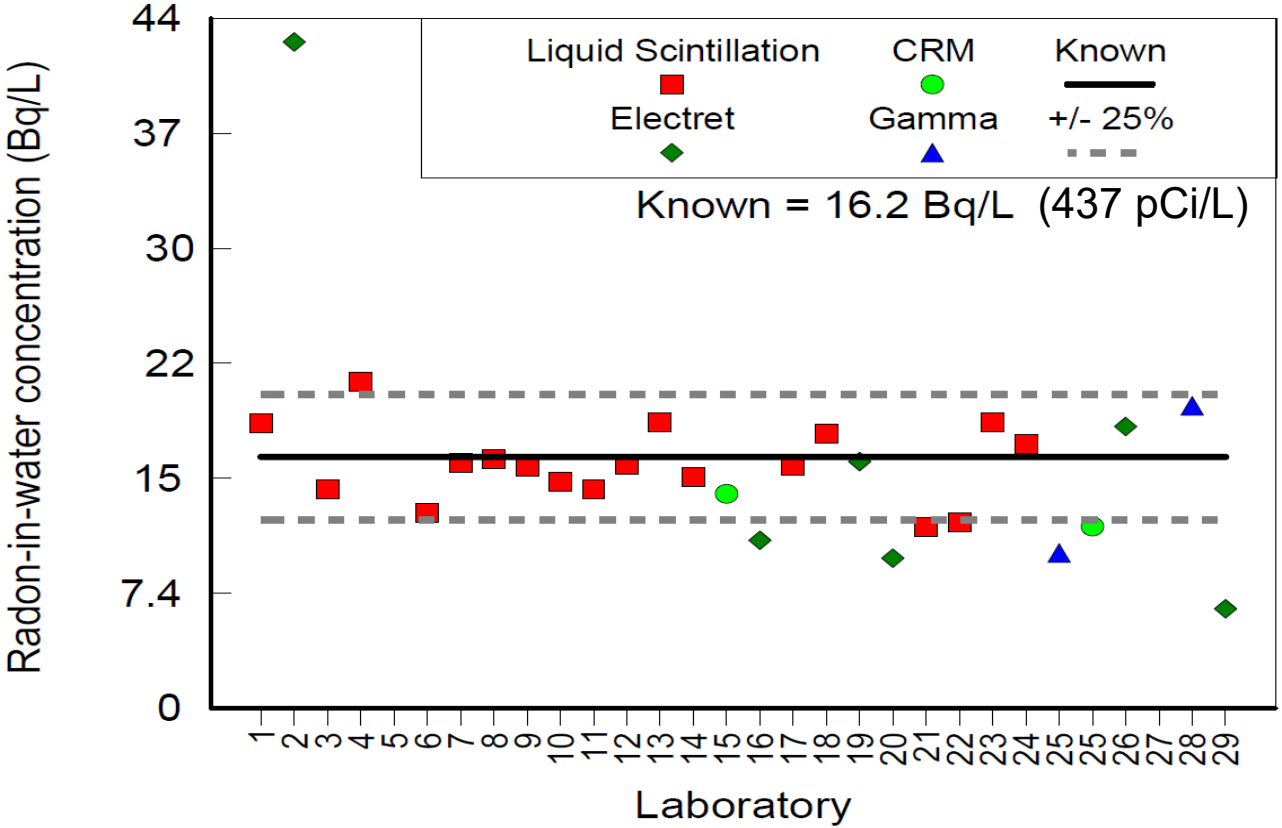
Kitto, Radiation Measurements 45, 231-233 (2010)

RESULTS OF SECOND INTERCOMPARISON (2010)



Unpublished data, Michael Kitto

RESULTS OF THIRD INTERCOMPARISON (2016)



Unpublished data, Michael Kitto

SOURCES OF ERROR

Collection (radon loss) Do duplicates, and report highest concentration

Transfer (radon loss) Accounted for during standardization

Measurement

Calculation (equation, volume, decay, etc)

DETERMINE DECAY $N_t = N_0 e^{-\lambda t}$

Decay calculation = exp [-nlog(2) / half-life x decay period]

Start 24-hr measurement 24 hrs after collection

Decay to mid-point of count (24 + 12 hrs)

Decay Factor = exp(-0.693/3.82 days x 1.5 day) = 0.76

Reduction of radon in water

- Storage (hold and decay)
- Blending (mix in cleaner water)
- Granular Activated Charcoal (GAC)
- Aeration units

If radon concentration is

below 4000 pCi/L → charcoal or aeration

above 4000 pCi/L → aeration recommended

Conversion of radioactivity (Bq) to mass (micrograms)

$$-dN/dt = \lambda \times W/A \times 6.02 \times 10^{23}$$

-dN/dt = decay rate (dpm) (note: 1Bq = 60 dpm)

λ = rate constant (0.693/half life (in minutes))

W = weight (in grams)

A = atomic mass of the isotope (e.g., 226 for Ra-226)

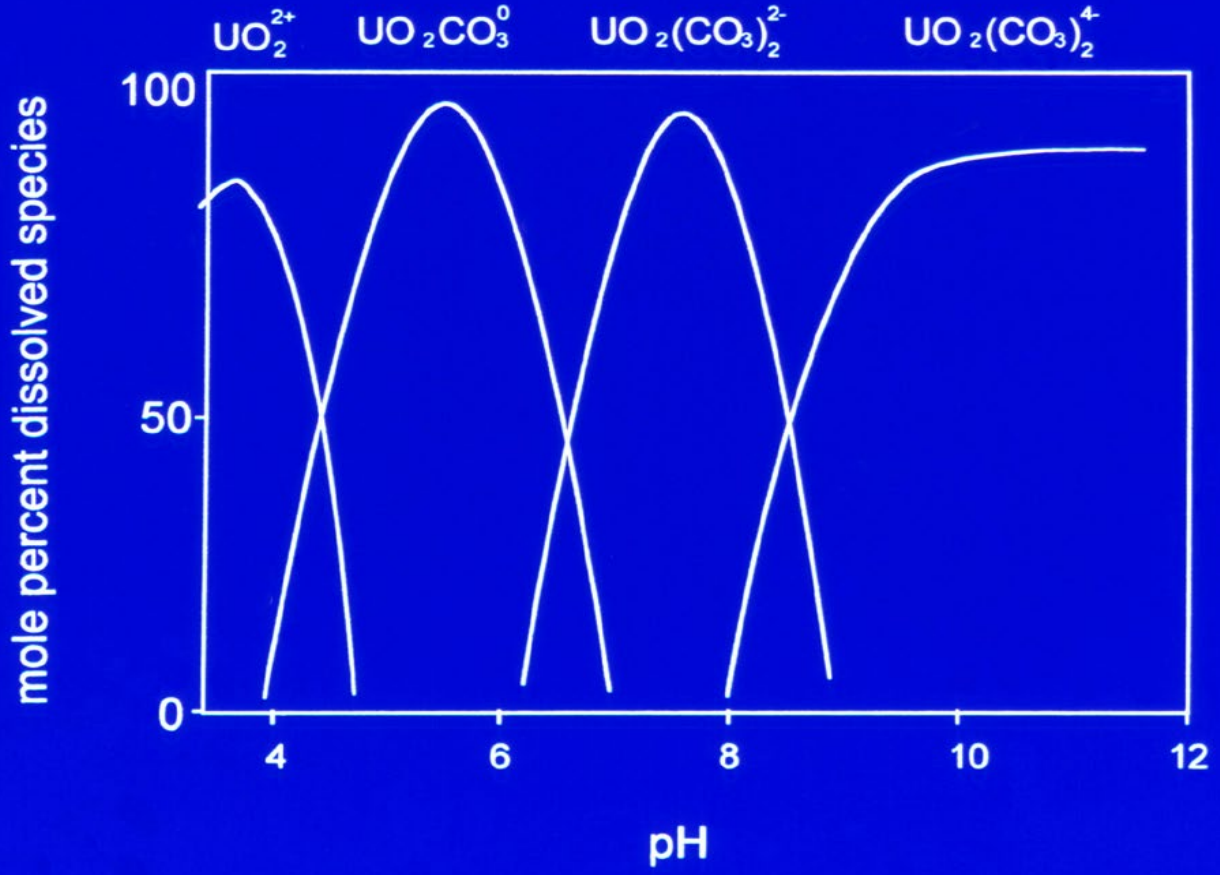
Isotope	Half life (yr)	Activity (in 1 ng)
Ra-226	1600	0.11 pCi
Ra-228	5.76	25.1 pCi

Isotope	Abund. %	Activity (in 1 ug)
U-234	0.006	0.32 pCi
U-235	0.72	0.016 pCi
U-238	99.27	0.32 pCi

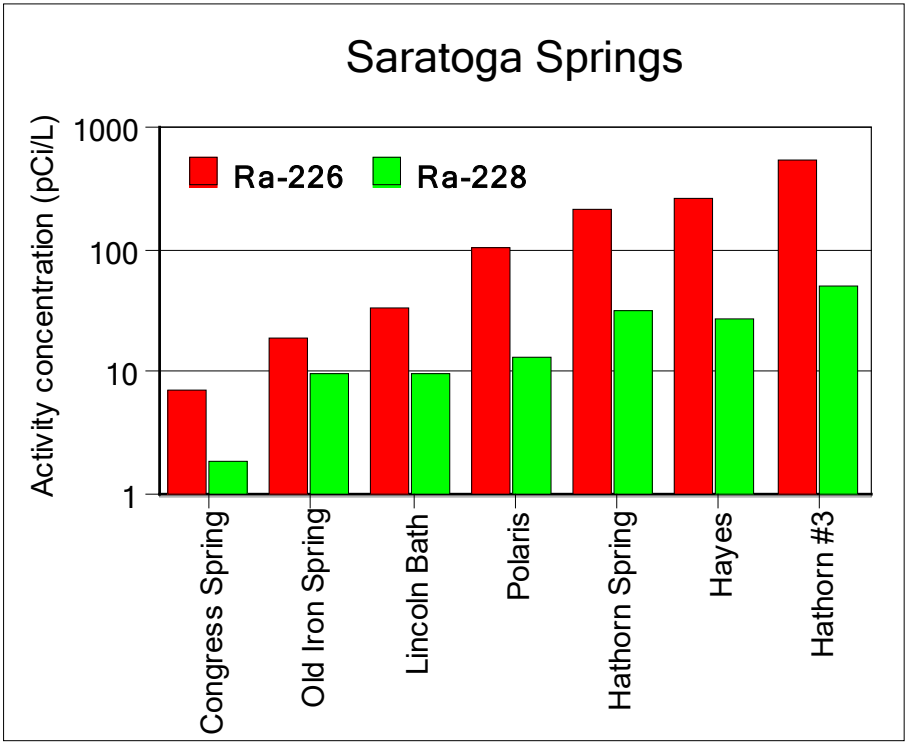
5/pCi/L ← EPA MCL → 30 ug/L (20 pCi/L)

These are measured as Gross Alpha (MCL= 15 pCi/L)

Distribution of uranyl hydroxy and carbonate complexes versus pH



High concentrations of radon occur in some spring waters and hot springs.



Saratoga Springs, NY

[Ra-226] quite high

but [Rn-222] very low

My sampling kit