Indoor Environments Association

Annual Radon and Vapor Intrusion Symposium

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RADON FROM SUBSLAB FILL

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Radon papers available at Researchgate.Net






UnExCo







2000 ft2 x 6" thick x 28320 cm3/ft3 x 2 g/cm3

or 56,600 kg (62 tons)



Reasons for study of subslab fill gravel:

- Investigate variability of uranium and thorium in subslab fill material
- Measure variation in radon emissions from fill materials
- Determine emanation rate and possible contribution to indoor radon levels

REMINDER : Subslab gravel is desirable (necessary?) for pressure field extension

Descriptions of stone aggregate samples

Mahoney-1 through Mahoney-8

- Collected from under slabs in the Albany, NY region

Costa-1 through Costa-10

- Collected from under slabs and gravel pits in central MA

All gravel was washed and air dried prior to measurements



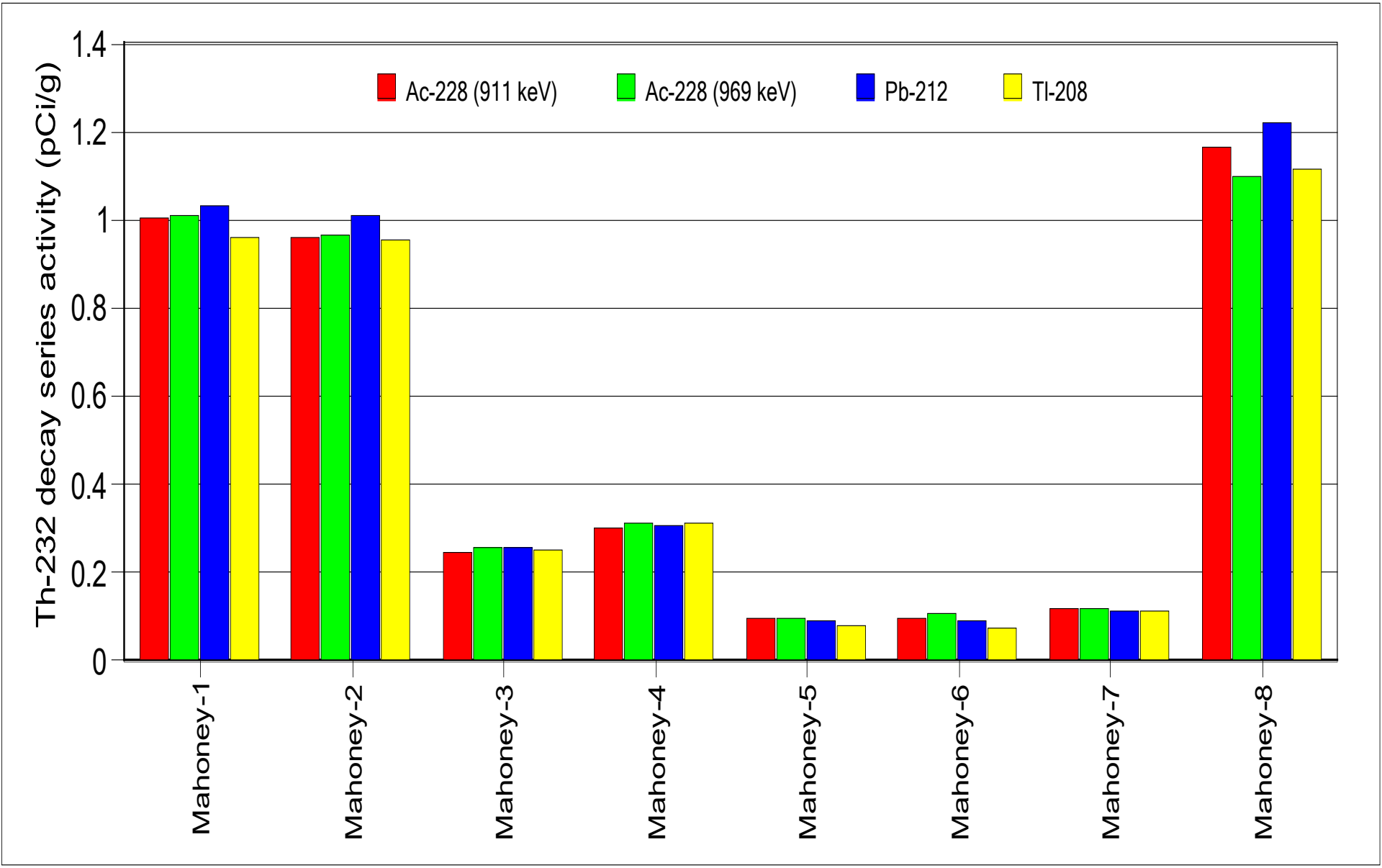
Naturally occurring radioactive decay series

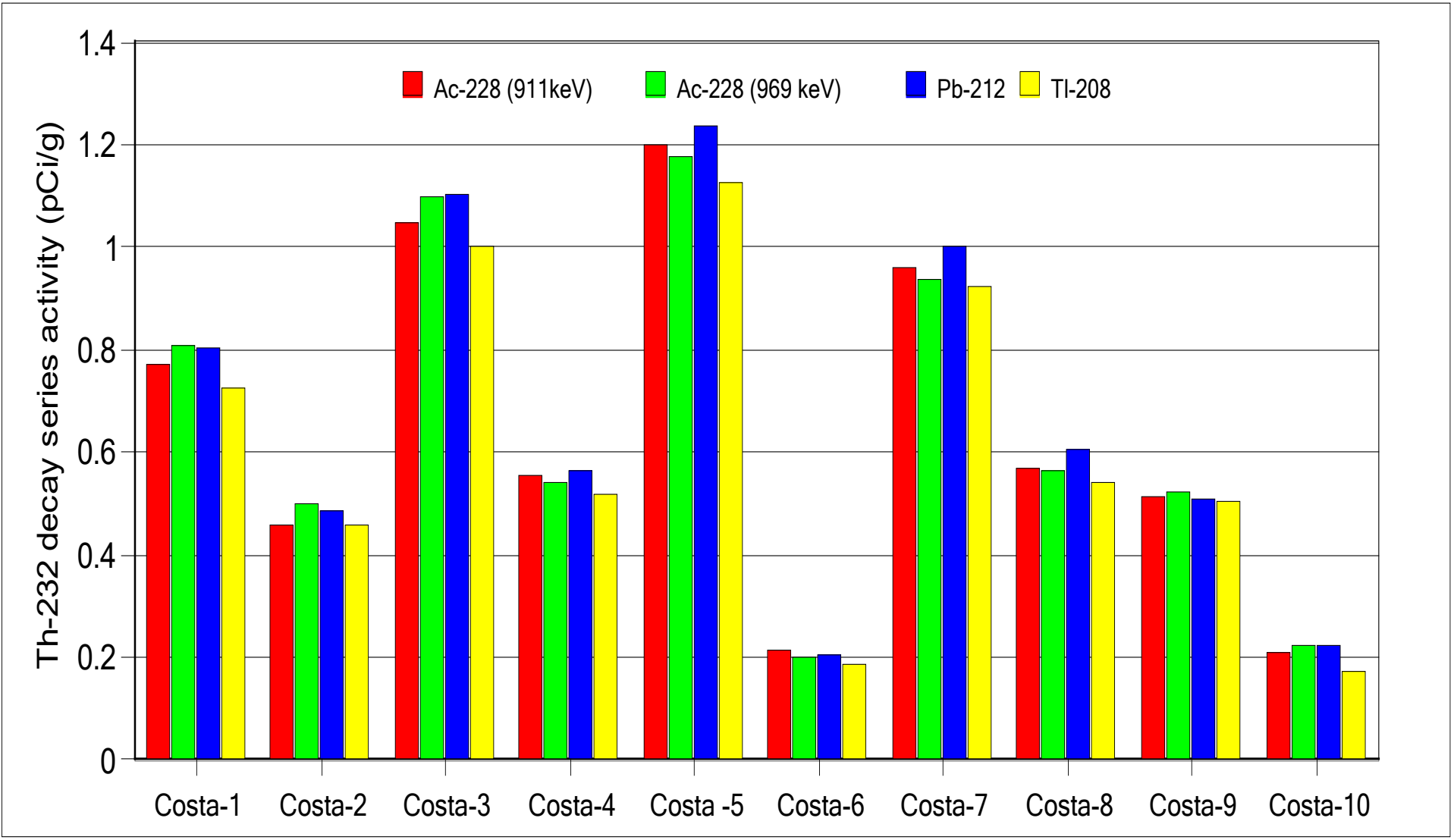
Parent of series	Parent half-life	
Thorium-232	14 billion years	99.9% of all Thorium
Uranium-238	4.5 billion years	99% of all Uranium
Uranium-235	0.7 billion years	0.7% of all Uranium
Neptunium-237	2 million years	extinct

Th-232 decay series

Thorium Series (4n)*

Nuclide	Historical name	Half-life	Major radiation energies (MeV) and intensities†		
			α	β	γ
$^{232}_{90}Th$	Thorium	1.41×10^{10}y	3.95 (24%) 4.01 (76%)	---	---
$^{228}_{88}Ra$	Mesothorium I	6.7y	---	0.055 (100%)	---
$^{228}_{89}Ac$	Mesothorium II	6.13h	---	1.18 (35%) 1.75 (12%) 2.09 (12%)	0.34c‡ (15%) 0.908 (25%) 0.96c (20%)
$^{228}_{90}Th$	Radiothorium	1.910y	5.34 (28%) 5.43 (71%)	---	0.084 (1.6%) 0.214 (0.3%)
$^{224}_{88}Ra$	Thorium X	3.64d	5.45 (6%) 5.68 (94%)	---	0.241 (3.7%)
$^{220}_{86}Rn$	Emanation Thoron (Tn)	55s	6.29 (100%)	---	0.55 (0.07%)
$^{216}_{84}Po$	Thorium A	0.15s	6.78 (100%)	---	---
$^{212}_{82}Pb$	Thorium B	10.64h	---	0.346 (81%) 0.586 (14%)	0.239 (47%) 0.300 (3.2%)
$^{212}_{83}Bi$	Thorium C	60.6m	6.05 (25%) 6.09 (10%)	1.55 (5%) 2.26 (55%)	0.040 (2%) 0.727 (7%) 1.620 (1.8%)
64.0% / 36.0%					
$^{212}_{84}Po$	Thorium C'	304ns	8.78 (100%)	---	---
$^{208}_{81}Tl$	Thorium C''	3.10m	---	1.28 (25%) 1.52 (21%) 1.80 (50%)	0.511 (23%) 0.583 (86%) 0.860 (12%) 2.614 (100%)

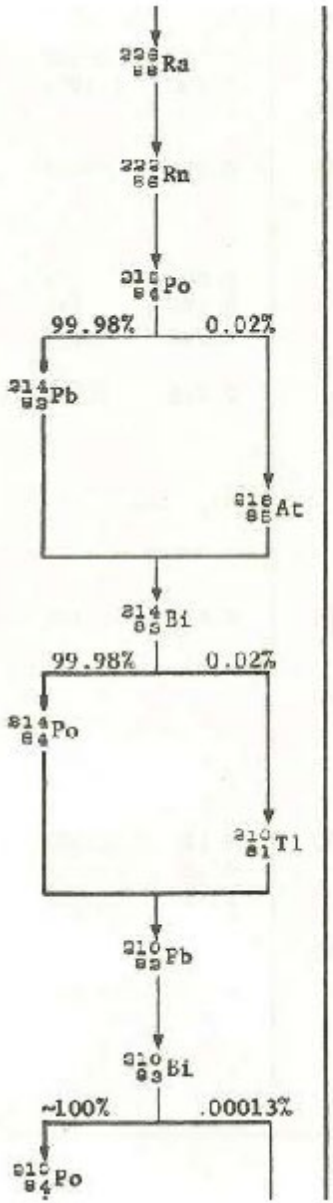

Th-232 decay series activity (pCi/g)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Ac-228 (911 keV)
Ac-228 (969 keV)
Pb-212
Tl-208
Mahoney-1
Mahoney-2
Mahoney-3
Mahoney-4
Mahoney-5
Mahoney-6
Mahoney-7
Mahoney-8


Ac-228 (911keV)
Ac-228 (969 keV)
Pb-212
Tl-208
Th-232 decay series activity (pCi/g)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Costa-1
Costa-2
Costa-3
Costa-4
Costa -5
Costa-6
Costa-7
Costa-8
Costa-9
Costa-10

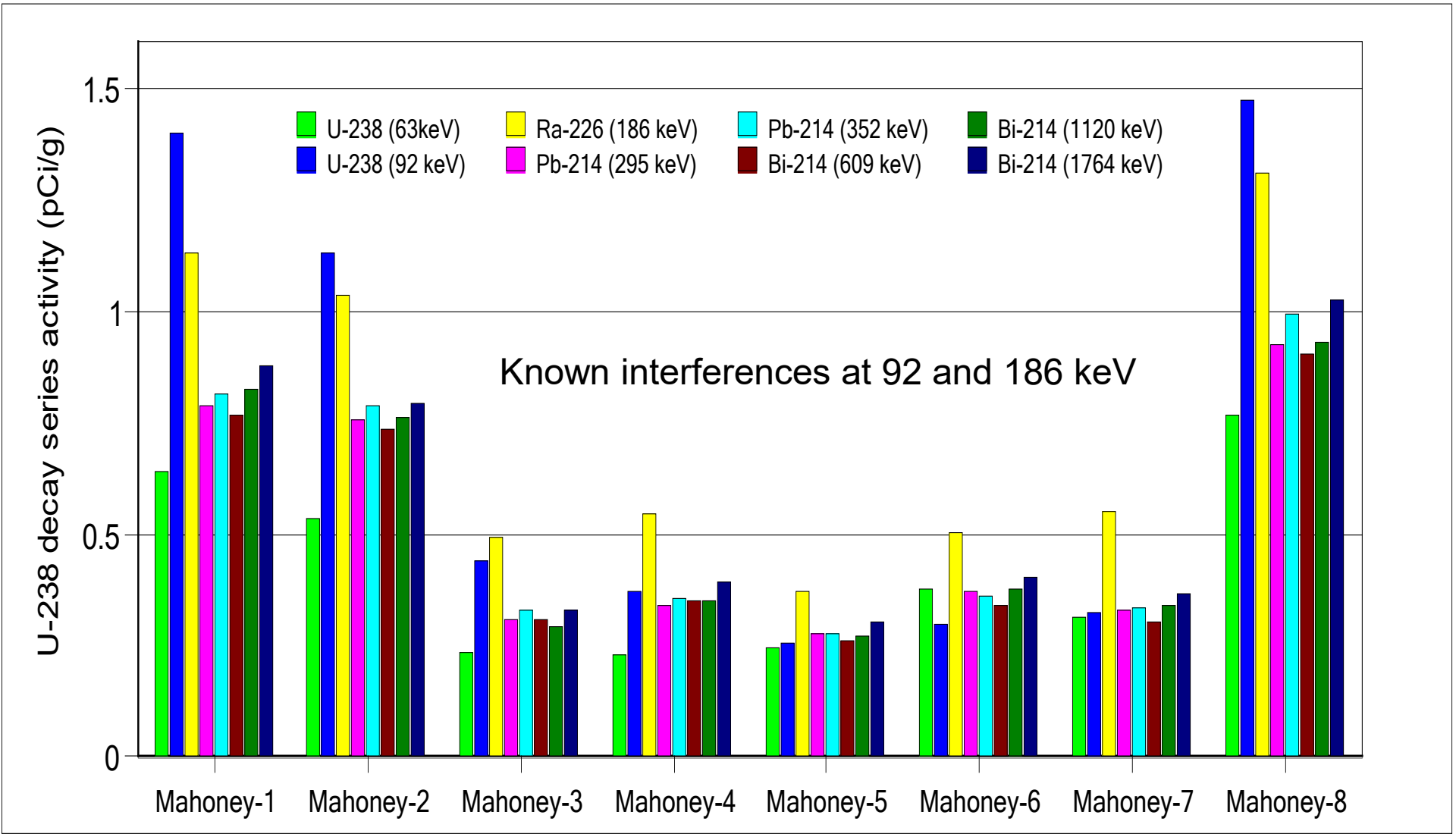
U-238 decay series

Uranium Series (4n + 2)*

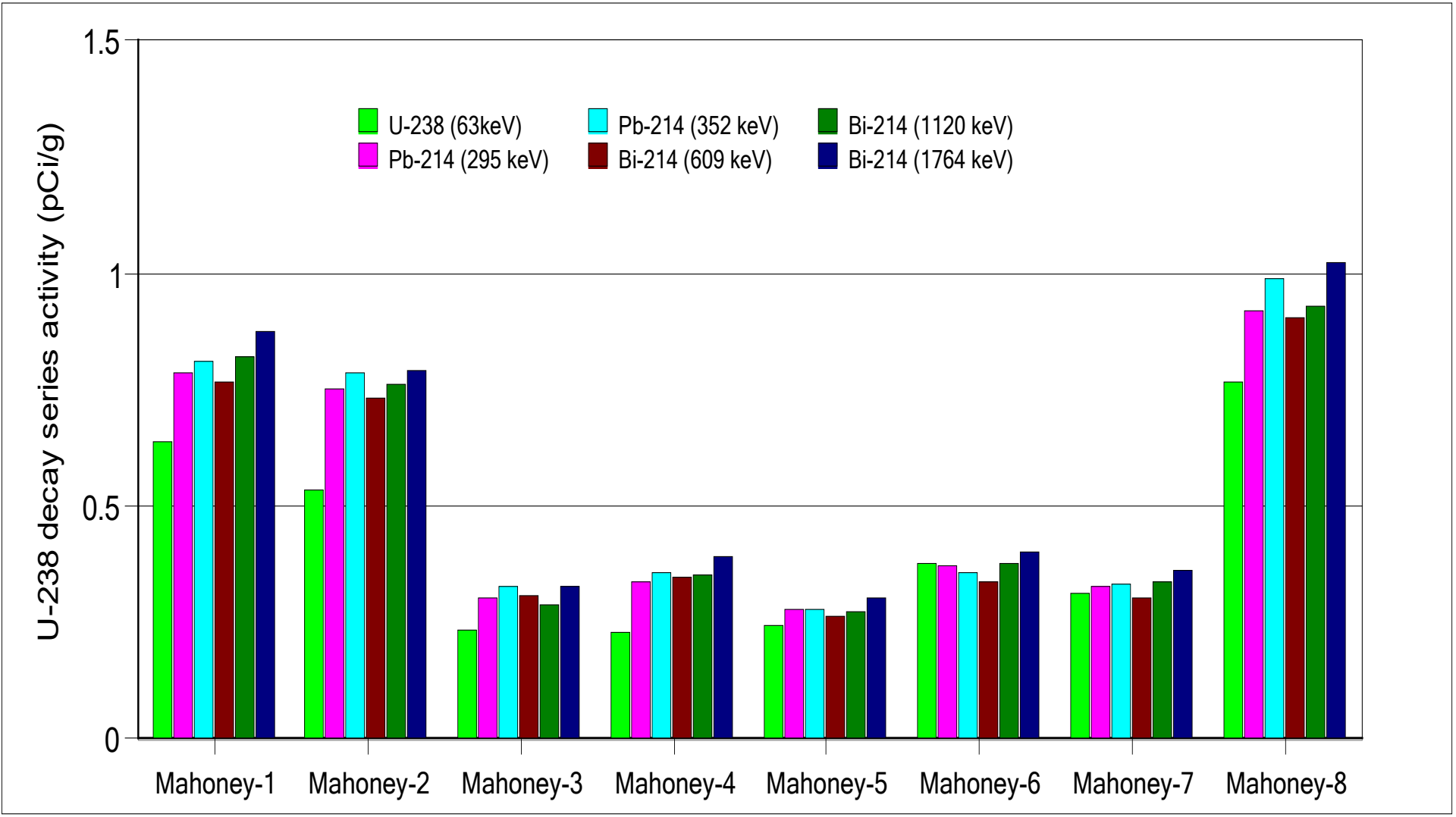
Nuclide	Historical name	Half-life	Major radiation energies (MeV) and intensities† α	β	γ
$^{238}_{92}U$	Uranium I	4.51×10^{9}y	4.15 (25%) 4.20 (75%)	---	---
$^{234}_{90}Th$	Uranium X_1	24.1d	---	0.103 (21%) 0.193 (79%)	0.063c‡ (3.5%) 0.093c (4%)
$^{234}_{91}Pa^{m}$	Uranium X_2	1.17m	---	2.29 (98%)	0.765 (0.30%) 1.001 (0.60%)
99.87% | 0.13%					
$^{234}_{91}Pa$	Uranium Z	6.75h	---	0.53 (66%) 1.13 (13%)	0.100 (50%) 0.70 (24%) 0.90 (70%)
$^{234}_{92}U$	Uranium II	2.47×10^{5}y	4.72 (28%) 4.77 (72%)	---	0.053 (0.2%)
$^{230}_{90}Th$	Ionium	8.0×10^{4}y	4.62 (24%) 4.68 (76%)	---	0.068 (0.6%) 0.142 (0.07%)
$^{226}_{88}Ra$	Radium	1602y	4.60 (6%) 4.78 (95%)	---	0.186 (4%)
$^{222}_{86}Rn$	Emanation Radon (Rn)	3.823d	5.49 (100%)	---	0.510 (0.07%)
$^{218}_{84}Po$	Radium A	3.05m	6.00 (~100%)	0.33 (~0.019%)	---
99.98% | 0.02%					
$^{214}_{82}Pb$	Radium B	26.8m	---	0.65 (50%) 0.71 (40%) 0.98 (6%)	0.295 (19%) 0.352 (36%)
$^{218}_{85}At$	Astatine	~2s	6.65 (6%) 6.70 (94%)	? (~0.1%)	---
$^{214}_{83}Bi$	Radium C	19.7m	5.45 (0.012%) 5.51 (0.008%)	1.0 (23%) 1.51 (40%) 3.26 (19%)	0.609 (47%) 1.120 (17%) 1.764 (17%)
99.98% | 0.02%					
$^{214}_{84}Po$	Radium C'	164μs	7.69 (100%)	---	0.799 (0.014%)
$^{210}_{81}Tl$	Radium C''	1.3m	---	1.3 (25%) 1.9 (56%) 2.3 (19%)	0.296 (80%) 0.795 (100%) 1.31 (21%)
$^{210}_{82}Pb$	Radium D	21y	3.72 (.000002%)	0.016 (85%) 0.061 (15%)	0.047 (4%)
$^{210}_{83}Bi$	Radium E	5.01d	4.65 (.00007%) 4.69 (.00005%)	1.161 (~100%)	---
~100% | .00013%					
$^{210}_{84}Po$	Radium F	138.4d	5.305 (100%)	---	0.803 (0.0011%)
$^{206}_{81}Tl$	Radium E''	4.19m	---	1.571 (100%)	---



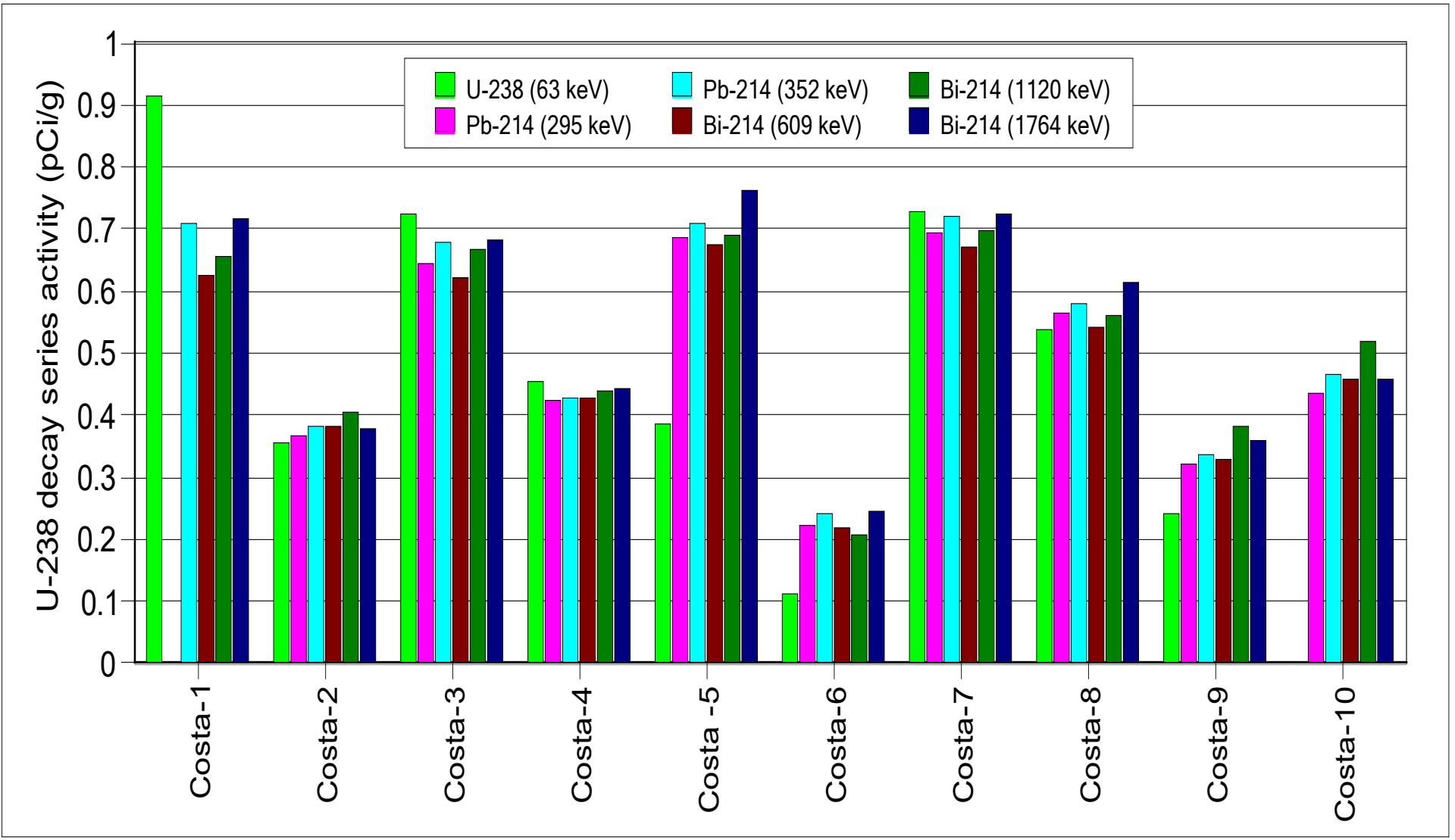
Radium	1602y	4.60 4.78	(6%) (95%)	---		0.186	(4%)
Emanation Radon (Rn)	3.823d	5.49	(100%)	---		0.510	(0.07%)
Radium A	3.05m	6.00	(~100%)	0.33	(~0.019%)	---	
Radium B	26.8m	---		0.65 0.71 0.98	(50%) (40%) (6%)	0.295 0.352	(19%) (36%)
Astatine	~2s	6.65 6.70	(6%) (94%)	?	(~0.1%)	---	
Radium C	19.7m	5.45 5.51	(0.012%) (0.008%)	1.0 1.51 3.26	(23%) (40%) (19%)	0.609 1.120 1.764	(47%) (17%) (17%)
Radium C'	164μs	7.69	(100%)	---		0.799	(0.014%)
Radium C''	1.3m	---		1.3 1.9 2.3	(25%) (56%) (19%)	0.296 0.795 1.31	(80%) (100%) (21%)
Radium D	21y	3.72	(.000002%)	0.016 0.061	(85%) (15%)	0.047	(4%)
Radium E	5.01d	4.65 4.69	(.00007%) (.00005%)	1.161	(~100%)	---	
Radium F	138.4d	5.305	(100%)	---		0.803	(0.0011%)



Gravel encapsulated for >30 days prior to gamma-ray measurements



Gravel encapsulated for >30 days prior to gamma-ray measurements



Gravel encapsulated for >30 days prior to gamma-ray measurements

Radon results

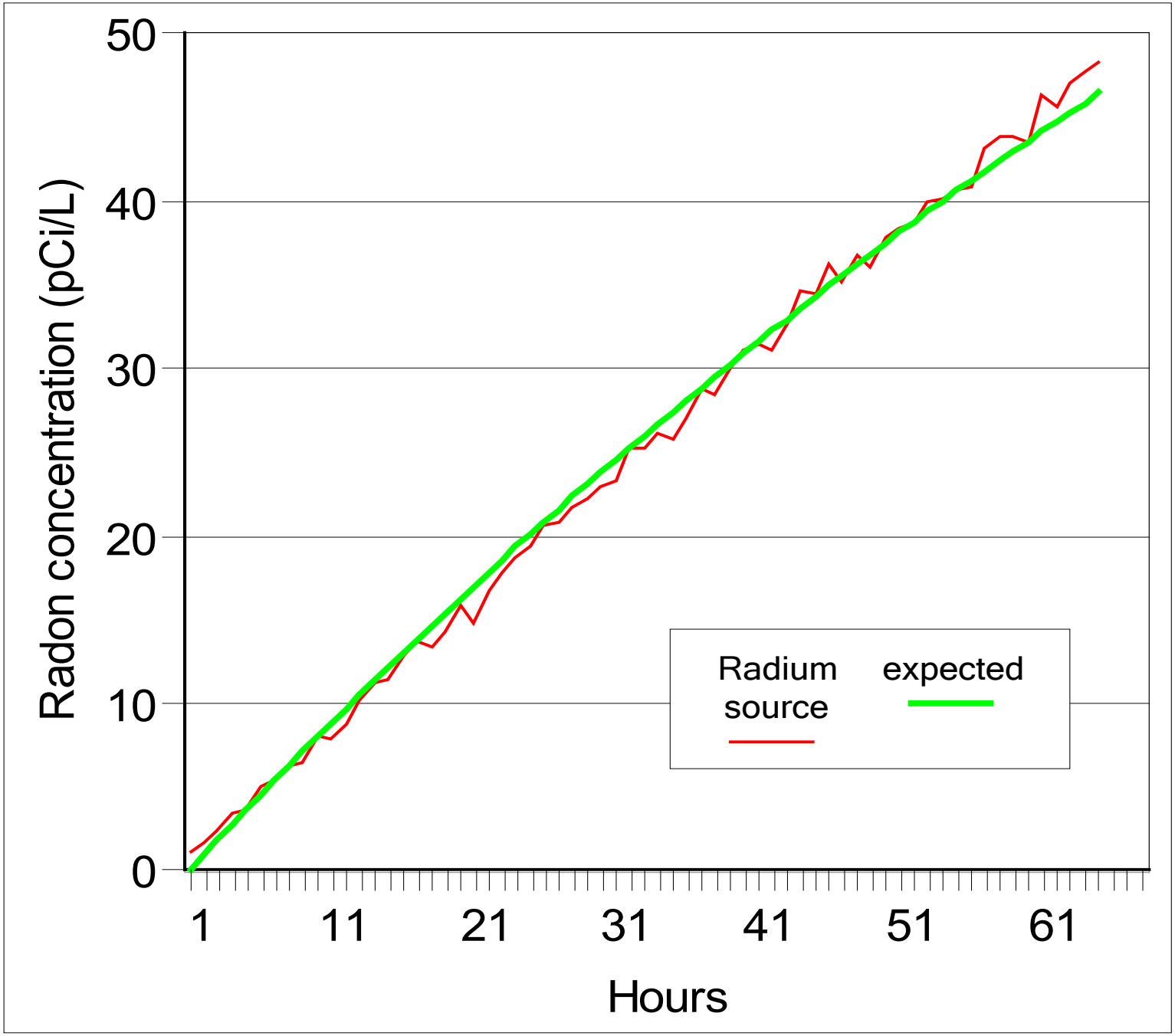


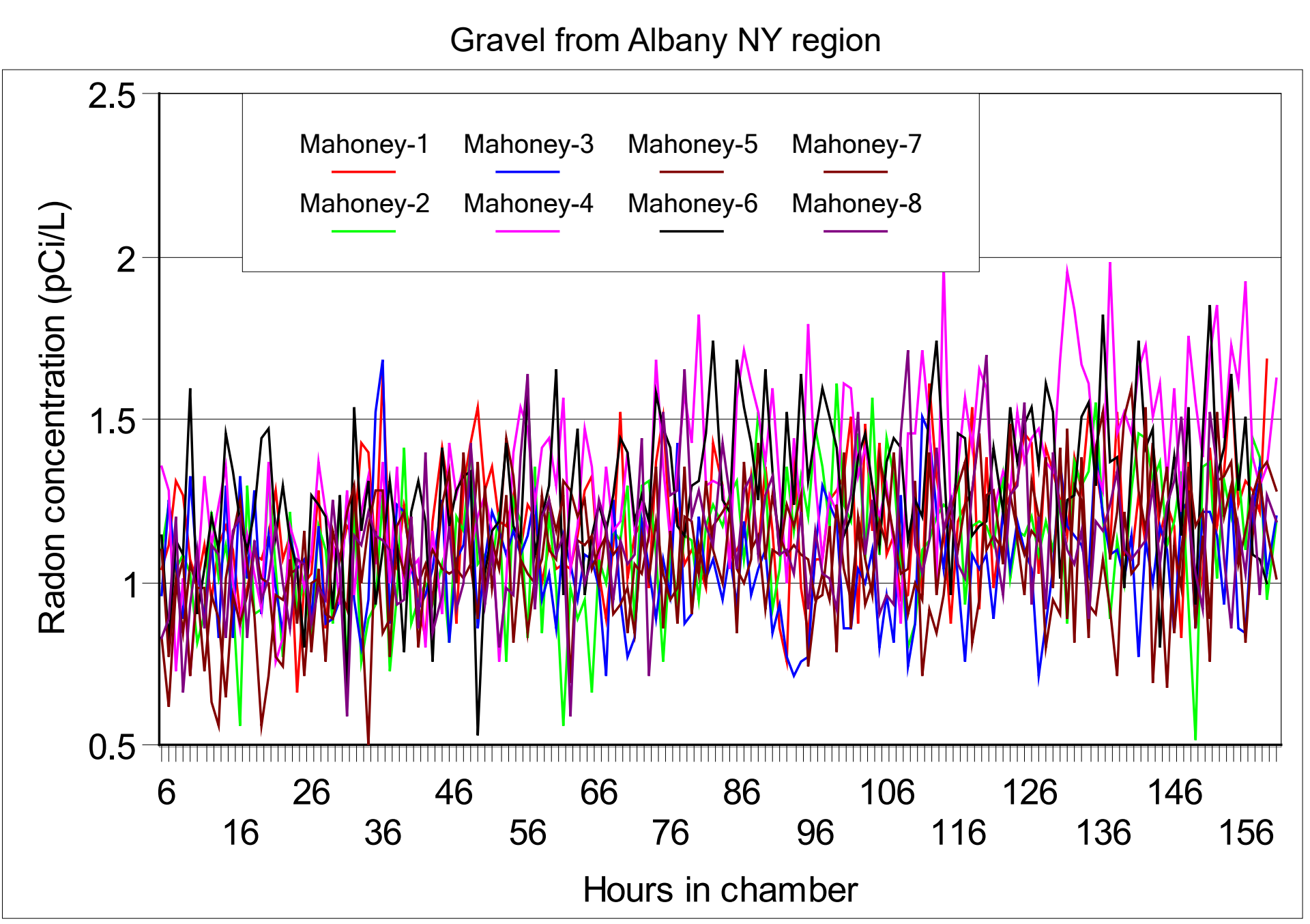
CRM inside airtight chamber.

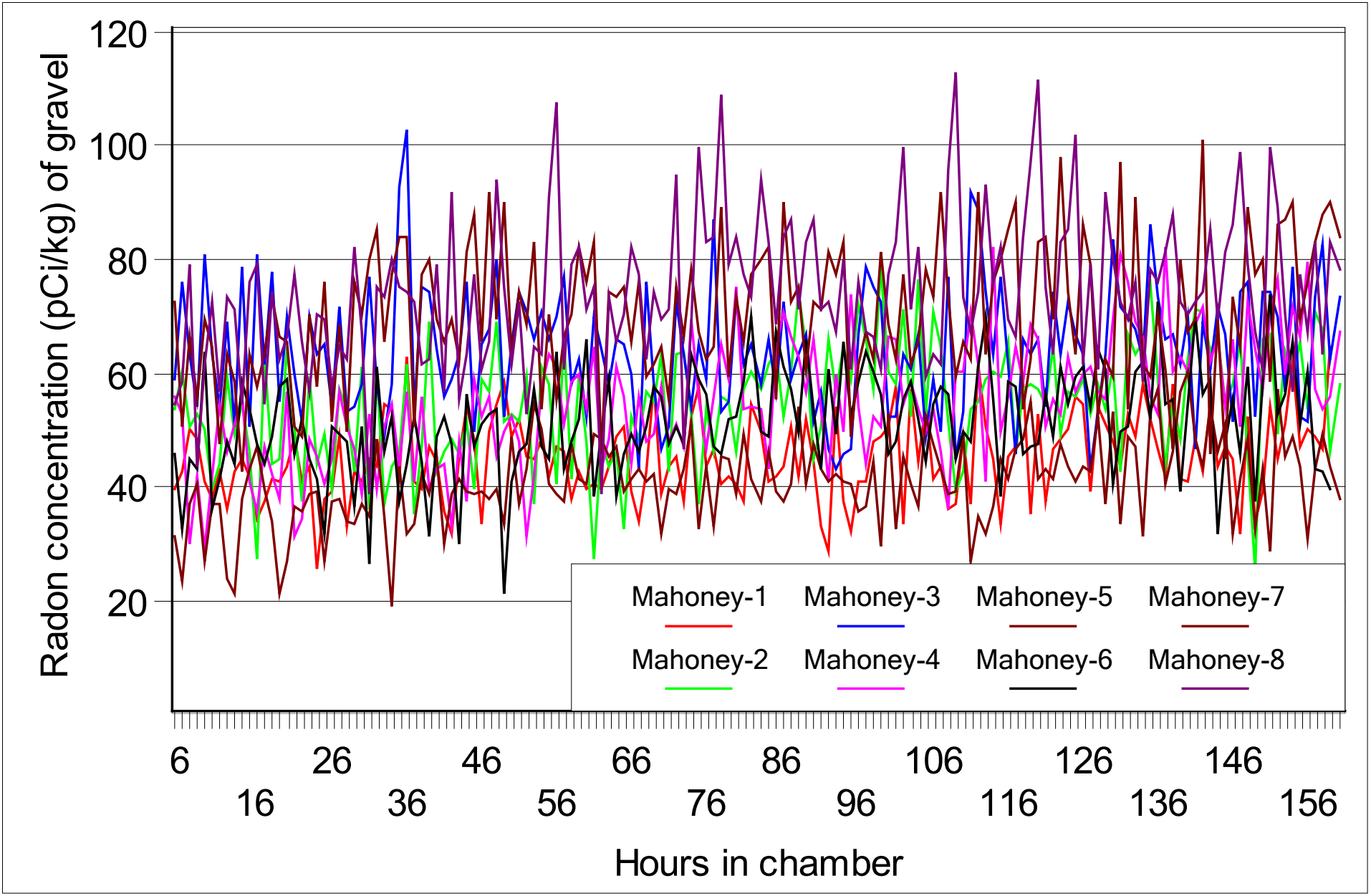
1-hr intervals for 7-8 days

700-900 g of each gravel

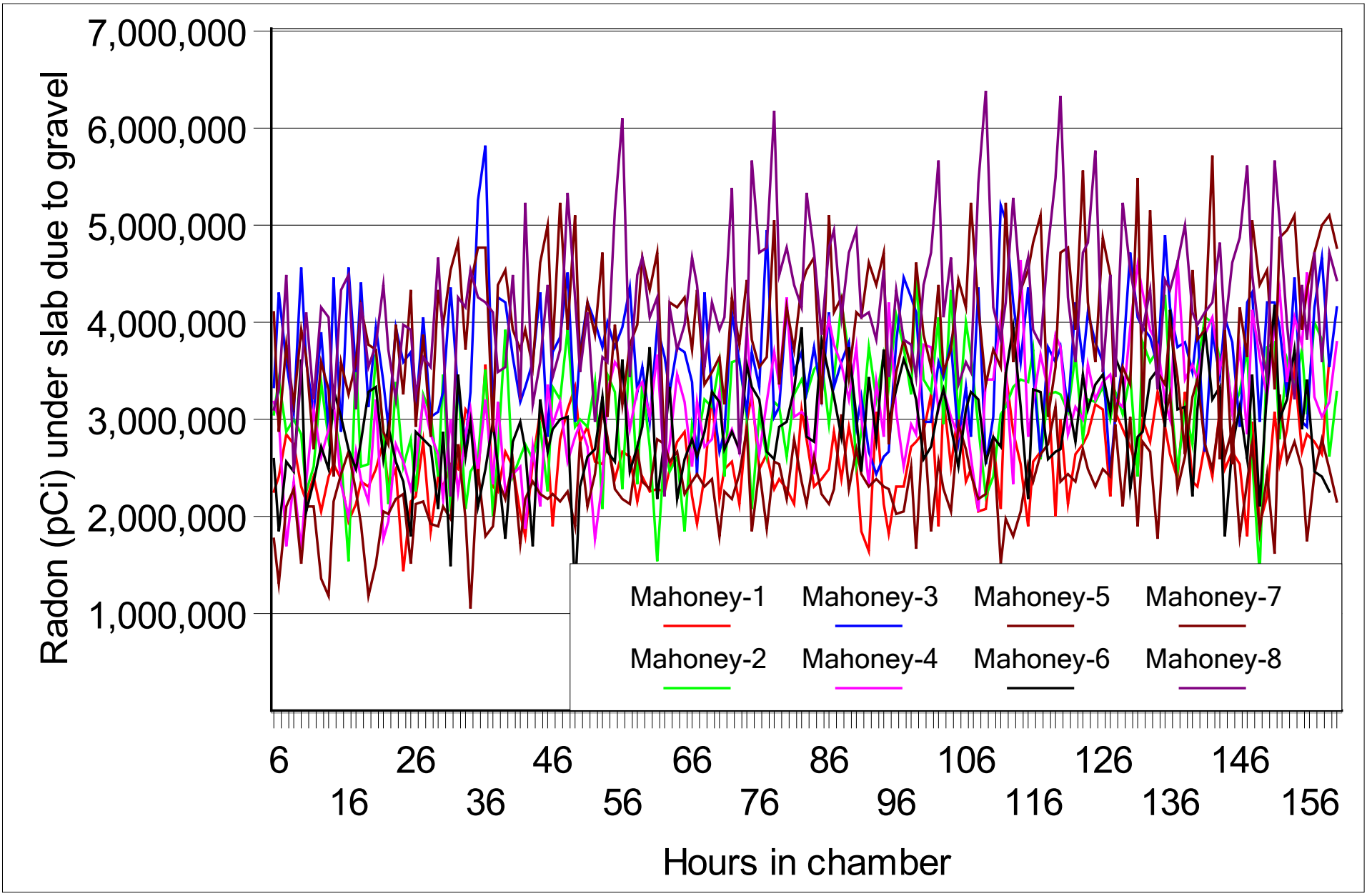
Ra-226 source in airtight box follows expected ingrowth




Gravel from Albany NY region
Mahoney-1
Mahoney-2
Mahoney-3
Mahoney-4
Mahoney-5
Mahoney-6
Mahoney-7
Mahoney-8
Radon concentration (pCi/L)
2.5
2
1.5
1
0.5
6
16
26
36
46
56
66
76
86
96
106
116
126
136
146
156
Hours in chamber

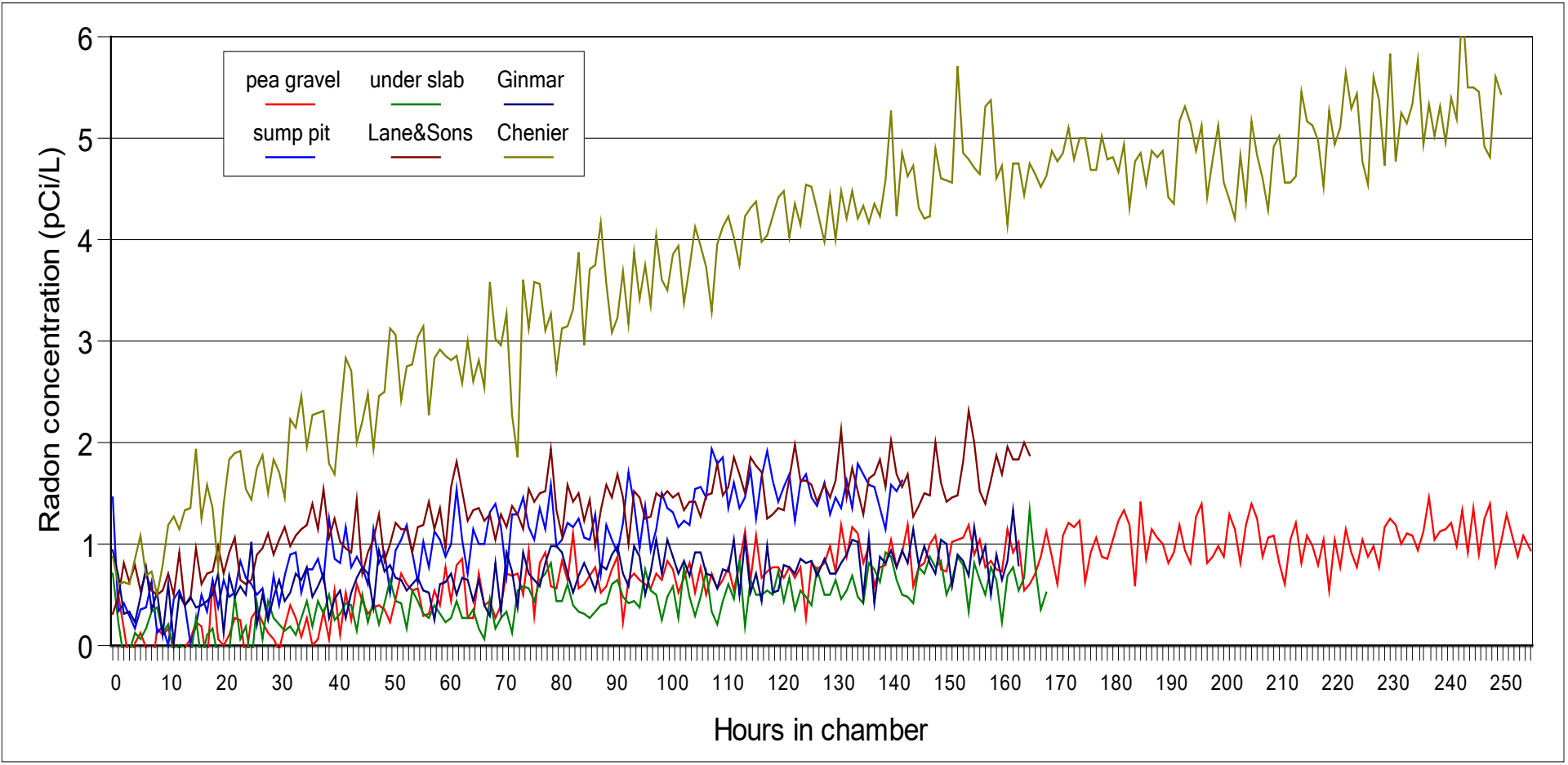


pCi of radon per kg of gravel in airtight box

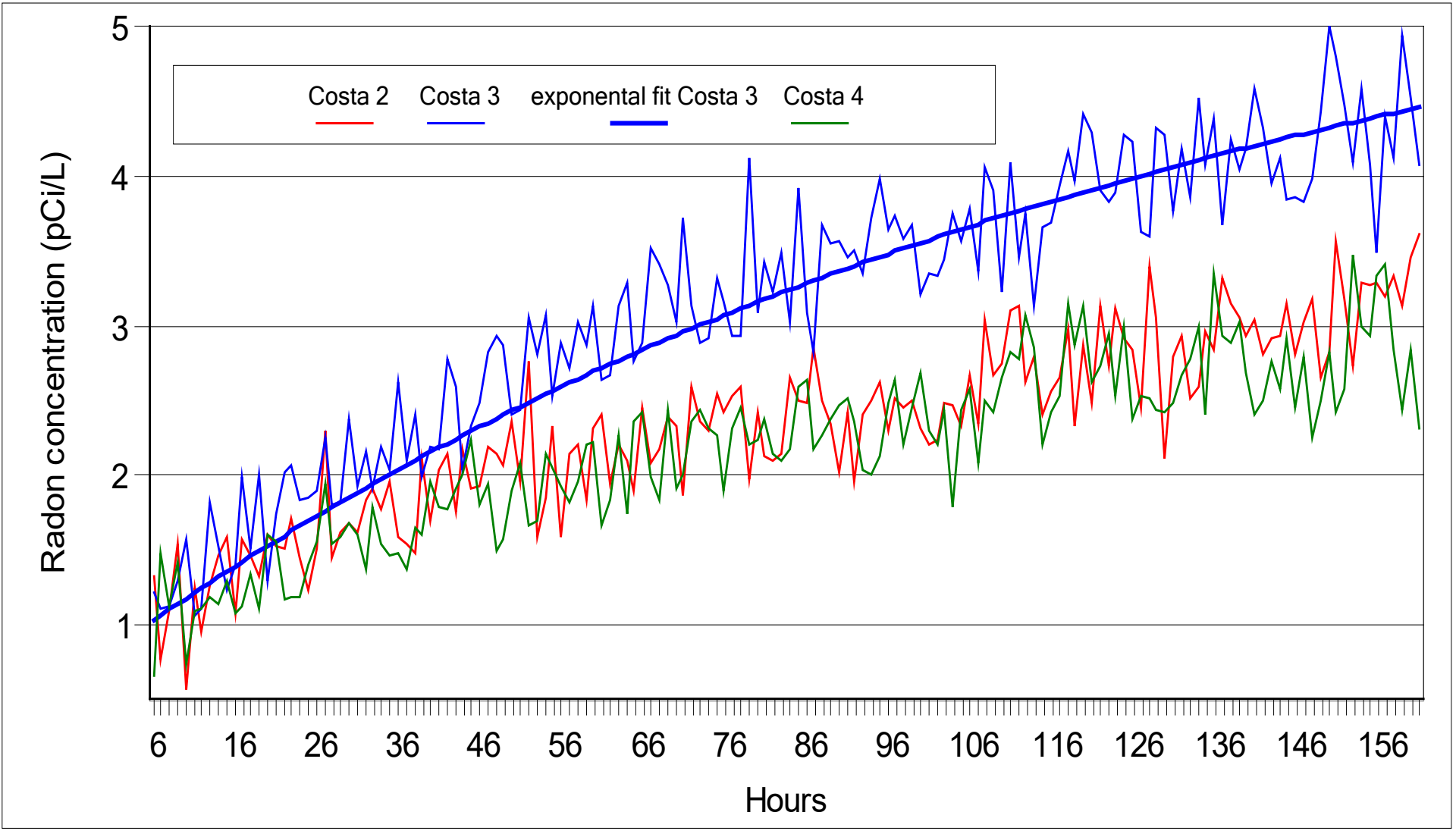

7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
Radon (pCi) under slab due to gravel
Mahoney-1
Mahoney-3
Mahoney-5
Mahoney-7
Mahoney-2
Mahoney-4
Mahoney-6
Mahoney-8
6
16
26
36
46
56
66
76
86
96
106
116
126
136
146
156
Hours in chamber

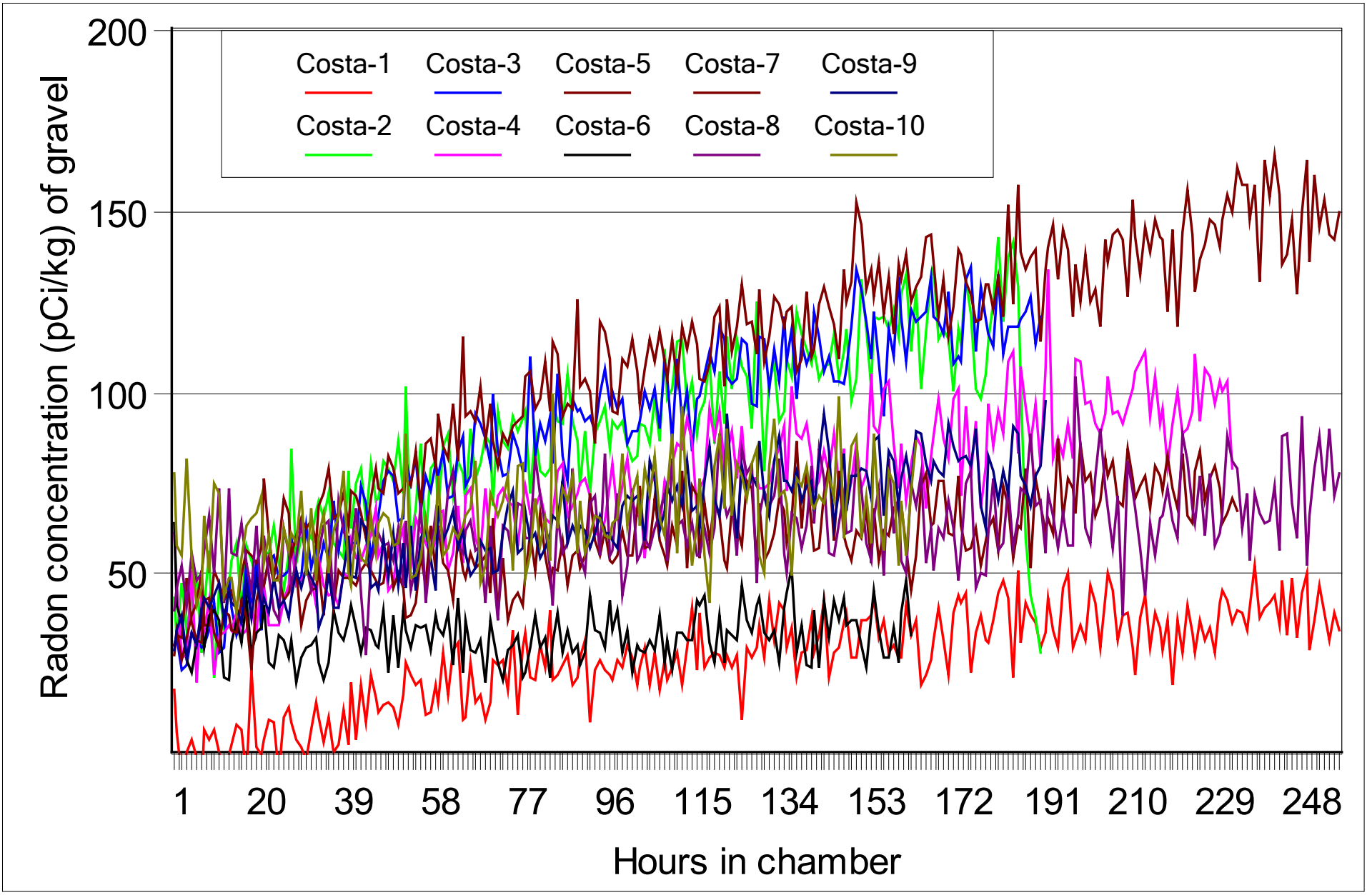
From central MA

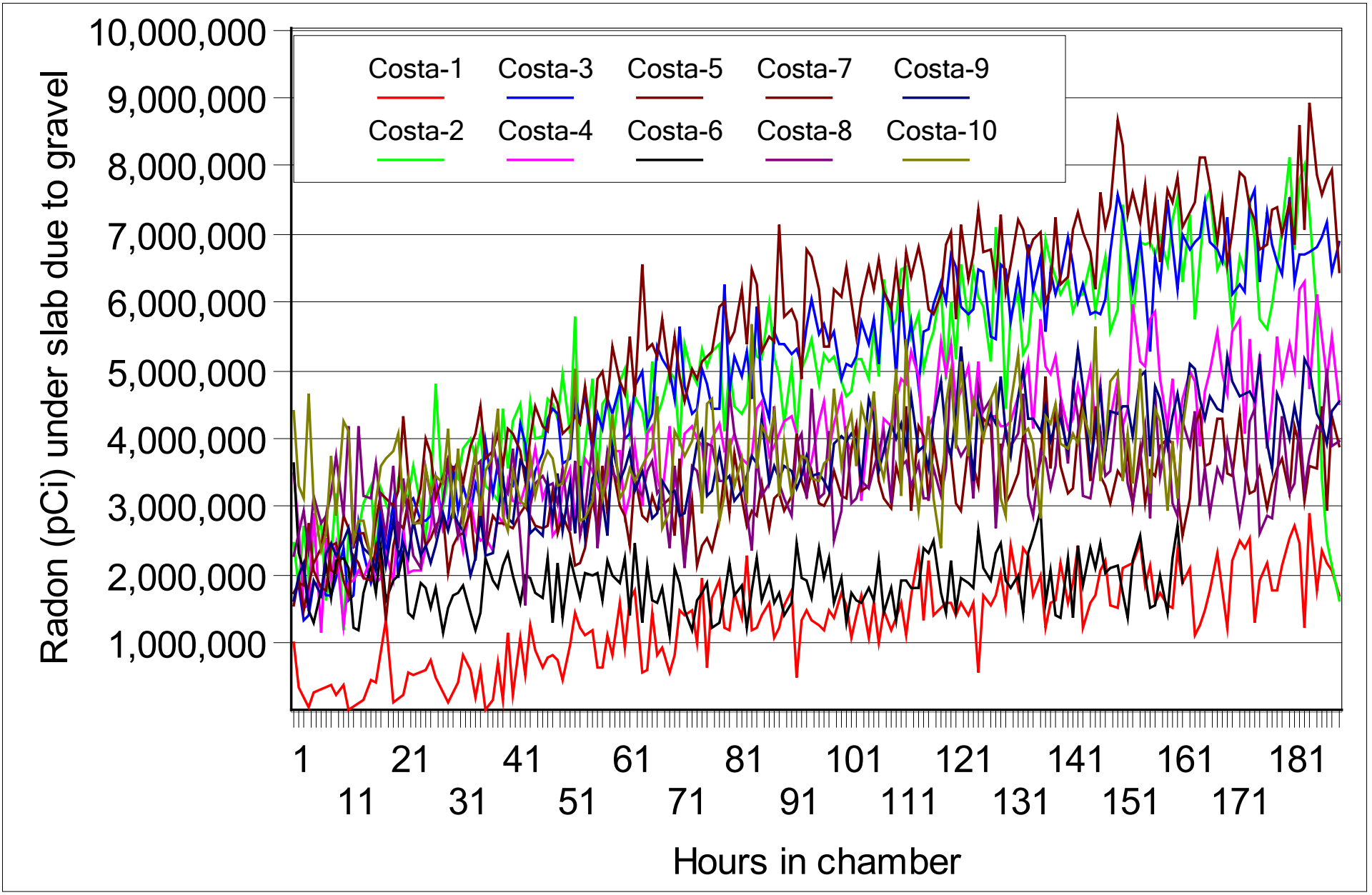
pCi/L of radon in airtight box

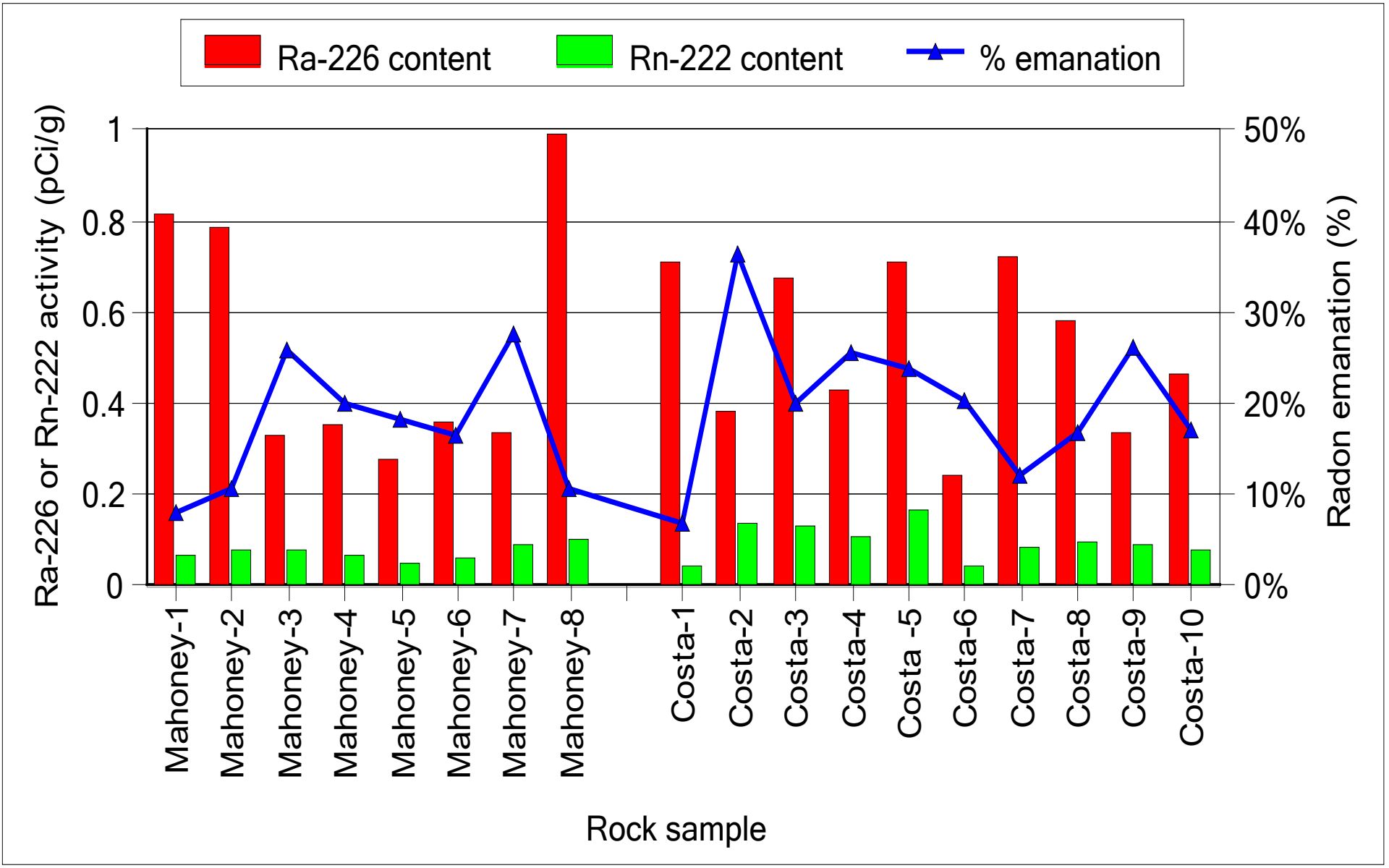


Radon ingrowth = 1-exp(-λ t)




Costa-1
Costa-3
Costa-5
Costa-7
Costa-9
Costa-2
Costa-4
Costa-6
Costa-8
Costa-10
200
150
100
50
Radon concentration (pCi/kg) of gravel
1
20
39
58
77
96
115
134
153
172
191
210
229
248
Hours in chamber


Costa-1
Costa-3
Costa-5
Costa-7
Costa-9
Costa-2
Costa-4
Costa-6
Costa-8
Costa-10
10,000,000
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
Radon (pCi) under slab due to gravel
1
11
21
31
41
51
61
71
81
91
101
111
121
131
141
151
161
171
181
Hours in chamber


Ra-226 content
Rn-222 content
% emanation
Ra-226 or Rn-222 activity (pCi/g)
Radon emanation (%)
1
0.8
0.6
0.4
0.2
0
50%
40%
30%
20%
10%
0%
Mahoney-1
Mahoney-2
Mahoney-3
Mahoney-4
Mahoney-5
Mahoney-6
Mahoney-7
Mahoney-8
Costa-1
Costa-2
Costa-3
Costa-4
Costa -5
Costa-6
Costa-7
Costa-8
Costa-9
Costa-10
Rock sample

For all 8 Mahoney gravels, the emanation of radon from the gravel ranged from 8% to 27% of the Ra-226 concentration (average=17%)

For all 10 Costa gravels, the emanation of radon from the gravel ranged from 7% to 36% of the Ra-226 concentration (average=20%)

From Slide #5: 56,600 kg of subslab fill
From Slide #23: 0.4 pCi/g radon and 20% emanation

56,600,000 * 0.4 * 0.2 = 4.5 million pCi of radon emitted from fill



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

Houses with low indoor air pressures
poorly sealed foundations
other entry points for soil air

may draw up to 20% of their indoor air from the soil.

Example:

Rn-222 at 4pCi/L in a 2000 ft2 basement ~ 1.8 million pCi in air

subslab outdoor air

(1% **x** 453 m3 air **x** ? pCi/L) **+** (99% x 453 m3 **x** 0.4 pCi/L) = 1.8 million pCi

(4,530 L **x** ?pCi/L) **+** 179,000 pCi = 1.8 million pCi Solve for ?

Therefore, soil gas of **360 pCi/L** would be sufficient to produce 4 pCi/L in air

Porosity Ranges for Sediments

Material	Porosity (%)
well-sorted sand or gravel	25-50
sand and gravel, mixed	20-35
glacial till	10-20
silt	35-50
clay	33-60

(Based on Meinzer (1923a); Davis (1969); Cohen (1965); and MacCary and Lambert (1962) as quoted by C.W. Fetter [2])

If soil gas of 360 pCi/L is sufficient to produce 4 pCi/L in air, and

gravel of 2000 ft2 x 6” x 25% porosity = 7,000 L of void space

Then amount of radon under slab (in gravel) would be 2.5 million pCi

Conclusions

- Radium-226 content of gravels varied from 0.2 to 1.0 pCi / gram
- Radon-222 emission from gravels varied from 20 to 90 pCi/kg
- Little correlation between Ra-226 content and Rn-222 emanation.
- Amount (emission) of radon from 60 tons of gravel varies from 1-8 million pCi.
- “fines” were removed, so actual Rn-222 concentrations are likely greater

Unfortunately…….

Color of gravel does not indicate the radium content or radon emanation rate.

So, choose your source of gravel carefully.

Acknowledgements: Authors thank George Costa and Bob Mahoney for providing the gravel samples.