SOIL-GAS RADON INTERCOMPARISONS

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- SOIL-GAS RADON INTERCOMPARISON MEASUREMENTS – HISTORY
- SYSTEM OF SOIL-GAS RADON DATA STANDARDIZATION IN THE CZECH REPUBLIC
- SOIL-GAS RADON INTERCOMPARISON MEASUREMENT, CZECH REPUBLIC, 2010 (RIM 2010)

SOIL-GAS RADON INTERCOMPARISON MEASUREMENTS – HISTORY (1991 – 2002)

Badgastein, Austria, 1991

CLIFF, K. D. – HOLUB, R. F. – KNUTSON, E. O. – LETTNER, H. – SOLOMON, S. B. (1994): International intercomparison of measurements of radon and radon decay products, Badgastein, Austria, September, 29 - 30, 1991, published by National Radiological Protection Board, Chilton, Didcot, Oxon.

New York, U.S.A., 1995

HUTTER, A. R. – KNUTSON, E. O. (1998): An International intercomparison of soil gas radon and radon exhalation measurements, Health Physics, Vol. 74, pp. 108-114.

Prague, Czech Republic, 1996

NEZNAL, M. – NEZNAL, M. – SMARDA, J. (1997): Intercomparison measurement of soil-gas radon concentration, Radiation Protection Dosimetry, Vol. 72, pp. 139-144.

Buk (near Pribram), Czech Republic, 2002

NEZNAL, M. – NEZNAL, M. (2004): International intercomparison measurement of soil-gas radon concentration, of radon exhalation rate from building materials and of radon exhalation rate from the ground, in Radon investigations in the Czech Republic, edited by I. Barnet, M. Neznal and P. Pacherova (Czech Geological Survey and RADON v.o.s, Prague), Vol. 10, pp. 12-22.

Badgastein, Austria, 1991

Site for the measurement of soil-gas radon concentration was sloping, with an inclination of 35 – 40 degrees, partly meadow, partly under trees. There was a thin soil layer at the site, with the underlying rock having high permeability and porosity.

Soil-gas radon concentrations were reported by 7 participants.

Large spectrum of methods: soil-gas sampling using a small-diameter hollow steel probe and Lucas cells x soil-gas radon concentration calculated from measured radium concentration (assuming emanation coefficient 0.3 – 0.4 and porosity 0.4).

Different sampling depths: 15 – 80 cm.

Very large variability of soil-gas radon concentration at the test site.

⇒ no way to compare the results

Badgastein, Austria, 1991

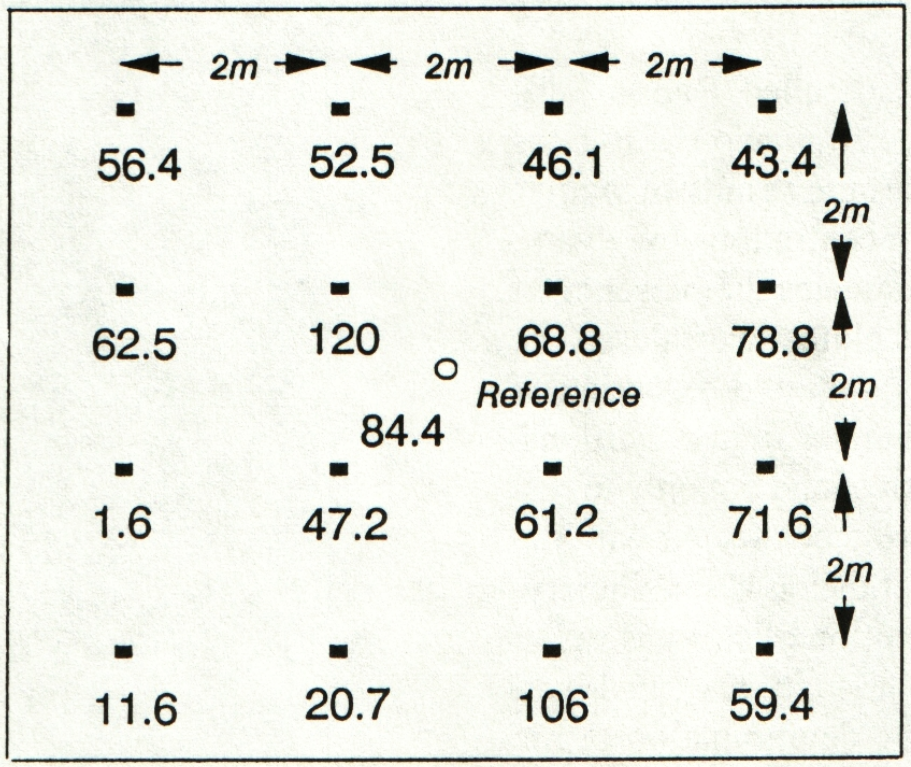


Fig. 1. Spatial variability of soil-gas radon concentration ($kBq \cdot m^{-3}$), Badgastein, Austria, 1991.

New York, U.S.A., 1995

First step: primary verification of Lucas cells in the Environmental Measurements Laboratory

Department of Energy
Environmental Measurements Laboratory
376 Hudson Street
New York, New York 10014

May 17, 1995

Dear Colleague:

The 27th EML Radon Gas Intercomparison was held on Monday, April 17, 1995. There were thirty participants, all of whom reported their data. As previously announced, the participating facilities and their results are identified in the summary table. order according to the before the name of the esults on two of the

27th EML RADON GAS INTERCOMPARISON (cont.)
April 17, 1995

	Bq ^{222}Rn m^{-3} Mean ± SD	Facility Mean EML PIC Mean
16 Radon Gas Detection, Harrisburg, PA	1066 ± 15	1.03 ± 0.02
17 radon v.o.s., Prague, CZECH REPUBLIC	1037 ± 21	1.00 ± 0.02
18 Rust Geotech Inc., Grand Junction, CO	982 ± 18	0.94 ± 0.02
19 St. John's University, Physics Dept, Collegeville, MN	1013 ± 68	0.97 ± 0.07
20 State of New York, Dept Heal, Off Public Health, Albany, NY	1089 ± 75	1.05 ± 0.07
21 State of New York, Dept Heal, Wadsworth Center, Albany, NY	983 ± 72	0.95 ± 0.07
22 Sun Nuclear Corp., Melbourne, FL	1028 ± 12	0.99 ± 0.02

ercise. The first graph alue reported by each a single value, so the graph depicts the ratio an value obtained at EML ents. The error bars d figure is a summary of since the beginning of

ice that the radon gas e held on a semi-annual the month of April, has invite comments on this erning the radon gas

ly,

Isabel M. Fisenne
Analytical Chemistry Division

Andreas C. George
Radiation Physics Division

New York, U.S.A., 1995

New Jersey, Cheesquake Parc, 16-06-1995

New York, U.S.A., 1995

The sampling area was an open field (meadow), bordered by woods on two sides and a paved parking area and a paved road on the other two sides. The site had a 2-m deep soil layer underlain by a 17-m layer of marl and sand, which was situated on top of metamorphic bedrock. The soil had alternating layers that were clay-rich and sand-rich.

Soil-gas radon concentrations were reported by 11 participants.

Different sampling depths: 0.4 – 0.5 m; 0.6 – 0.75 m; 0.9 – 1.0 m.

Variability of results described by the SD/mean ratio:

0.4 – 0.5 m	1.20
0.6 – 0.75 m	0.36
0.9 – 1.0 m	0.27

New York, U.S.A., 1995

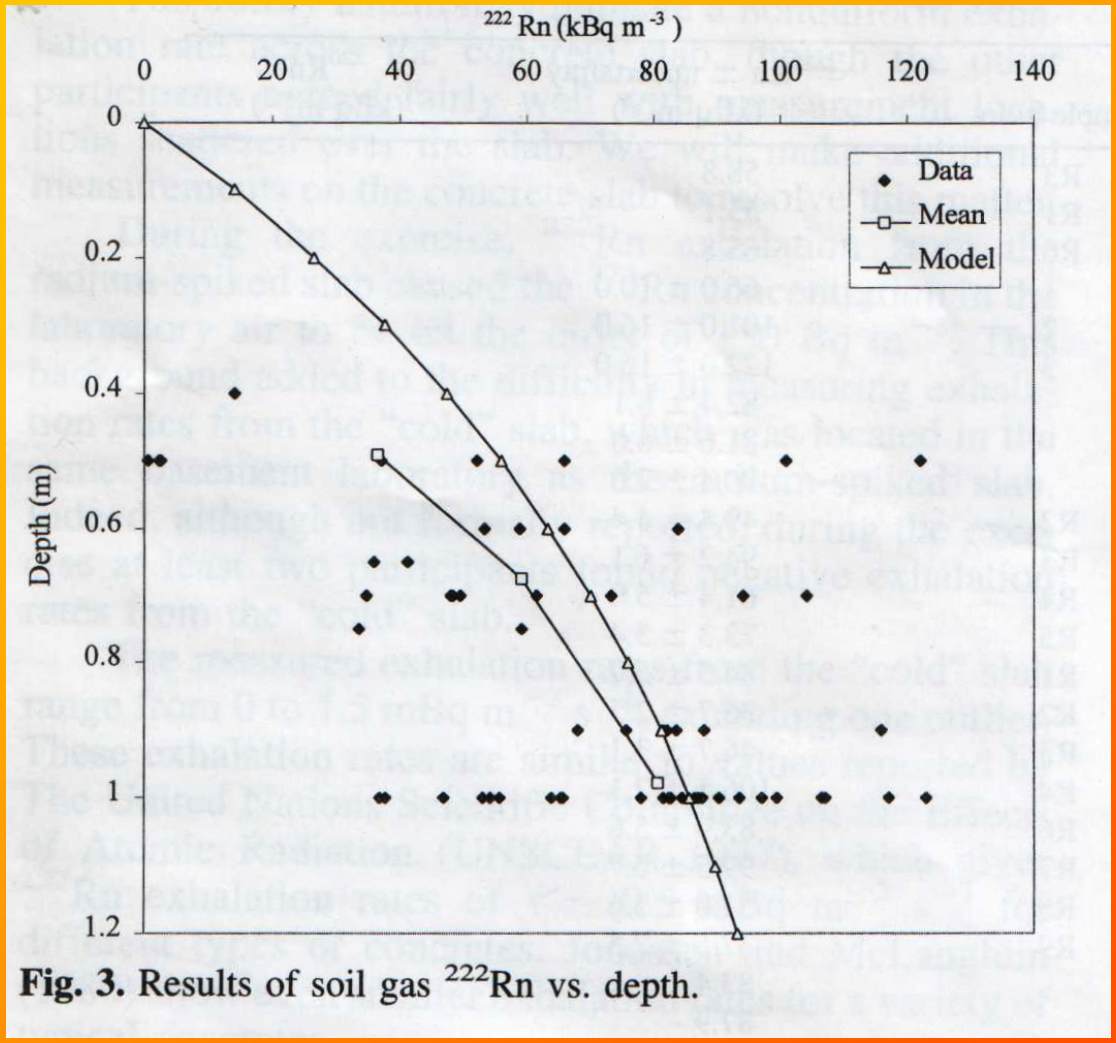


Fig. 3. Results of soil gas ^{222}Rn vs. depth.

Prague, Czech Republic, 1996

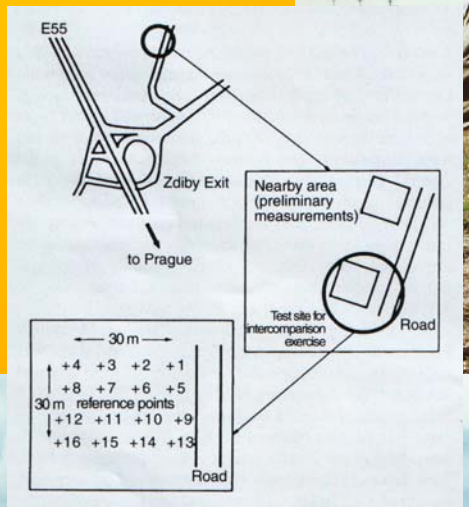


Figure 1. Location of the test site.

Zdiby, northern outskirts of Prague, 16-09-1996

Prague, Czech Republic, 1996

Test site:

open field (meadow), agriculturally cultivated (time after the harvest)

bedrock formed by Cretaceous marlites, bedrock weathering extensive and almost regular (clays, locally clayey sands)

clays covered by Tertiary sandy gravel fluvial and lacustrine sediments

the uppermost layer: Quarternary aeolic sediments – loess (3 – 4 m) covered by organic rich clayey loam (0.5 m)

Permeability of soil: medium to low

In situ measurements at the depth of 1 m: 0.1×10^{-13} – 5.5×10^{-13} m^2

Content of natural radionuclides in loess samples:

^{238}U: 72 – 91 Bq/kg **^{226}Ra: 50 – 62 Bq/kg**

^{232}Th: 41 – 51 Bq/kg **^{40}K: 564 – 624 Bq/kg**

Soil-gas radon concentrations reported by 10 participants

Prague, Czech Republic, 1996

Results

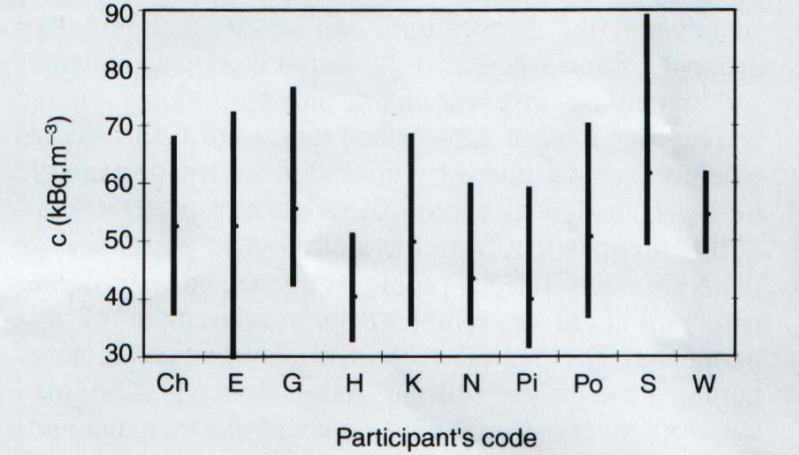


Figure 2. Intercomparison of soil-gas radon concentration (c) data reported by different participants.

Variability with depth described by the SD/mean ratio:

0.6 - 0.7 m	**0.25**
0.75 – 0.8 m	**0.21**
0.9 – 1.0 m	**0.25**

Prague, Czech Republic, 1996

Results – spatial variability

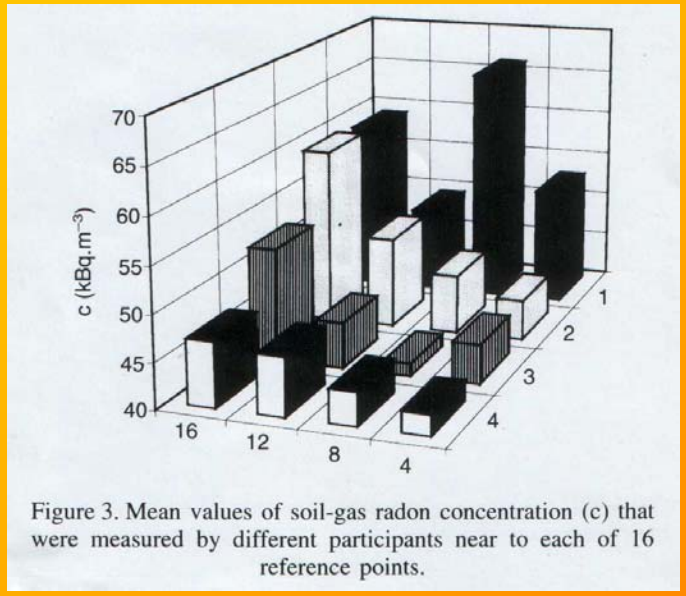


Figure 3. Mean values of soil-gas radon concentration (c) that were measured by different participants near to each of 16 reference points.

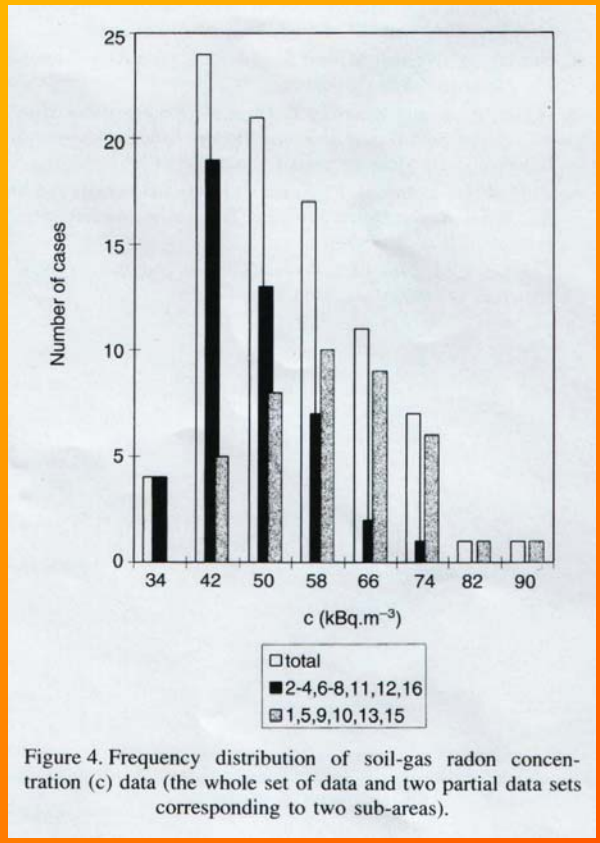


Figure 4. Frequency distribution of soil-gas radon concentration (c) data (the whole set of data and two partial data sets corresponding to two sub-areas).

Spatial variability described by the SD/mean ratio:

points 1, 5, 9, 10, 13, 14, 15	0.21
points 2, 3, 4, 6, 7, 8, 11, 12, 16	0.20

Buk (near Pribram), Czech Republic, 2002

+ 1	*5m*	+ 2	+ 3	+ 4
5m				
+ 5		+ 6	+ 7	+ 8
+ 9		+ 10	+ 11	+ 12

road Buk - Radetice

Buk, 20-09-2002

Buk (near Pribram), Czech Republic, 2002

Test site:

Geological basement is formed by a medium grained biotitic and amphibol-biotitic granodiorite (Milin type) of the Central Bohemian pluton of Paleozoic age. The eluvial granitic material forms the cover.

Expected values of soil gas radon concentration are relatively high, soil is highly permeable at the test site. A meadow is on the surface.

(Matolin, M. Radon Reference Sites in the Czech Republic. In: Barnet, I.; Neznal, M., eds. Radon Investigations in CR. Vol. 9. Praha: Czech Geological Survey and Radon corp.; 2002: 26-29)

Recommended sampling depth: 0.8 m

Soil-gas radon concentrations were reported by 8 participants.

Buk (near Pribram), Czech Republic, 2002

Results:

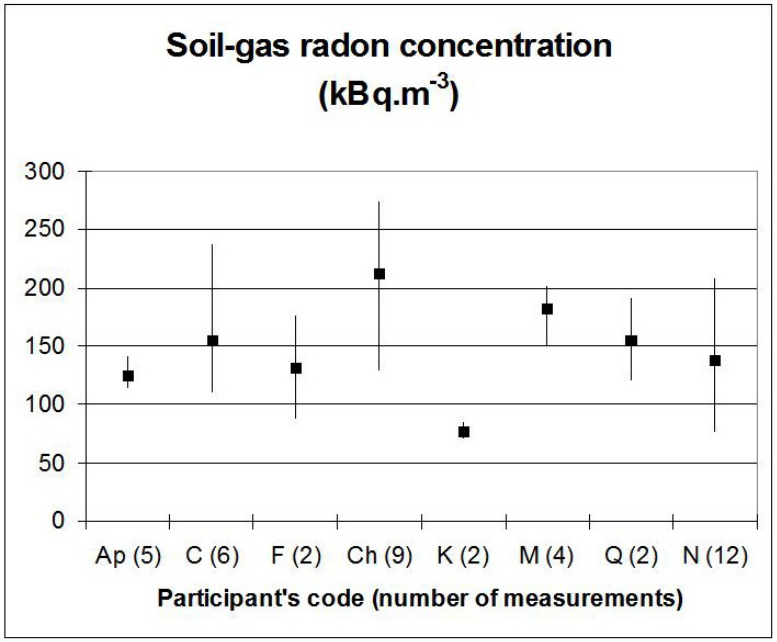


Figure 3. Intercomparison of soil-gas radon concentration data reported by different participants.

Table 7. Intercomparison of soil-gas radon concentration data reported by different participants.

Participant's code	Number of meas.	Sampling depths (m)	Soil-gas radon concentration (kBq.m^{-3})					
			min.	max.	median	mean	SD	SD/mean
Ap	5	0.55 - 0.6	114	141	124	125	9.9	0.08
C	6	0.8	109	238	143	155	45.8	0.30
F	2	0.8	87.0	176	(132)	132	62.9	0.49
Ch	9	0.8	129	274	232	213	54.7	0.26
K	2	0.52 - 0.7	70.0	85.0	(77.5)	77.5	10.6	0.14
M	4	0.8	150	201	191	183	22.8	0.12
Q	2	0.8	120	190	(155)	155	49.5	0.32
N	12	0.8	76.0	207	136	139	34.9	0.25
Total	42	0.55 - 0.8	70.0	274	145	157	51.9	0.33

Buk (near Pribram), Czech Republic, 2002

Results – variability with depth and time:

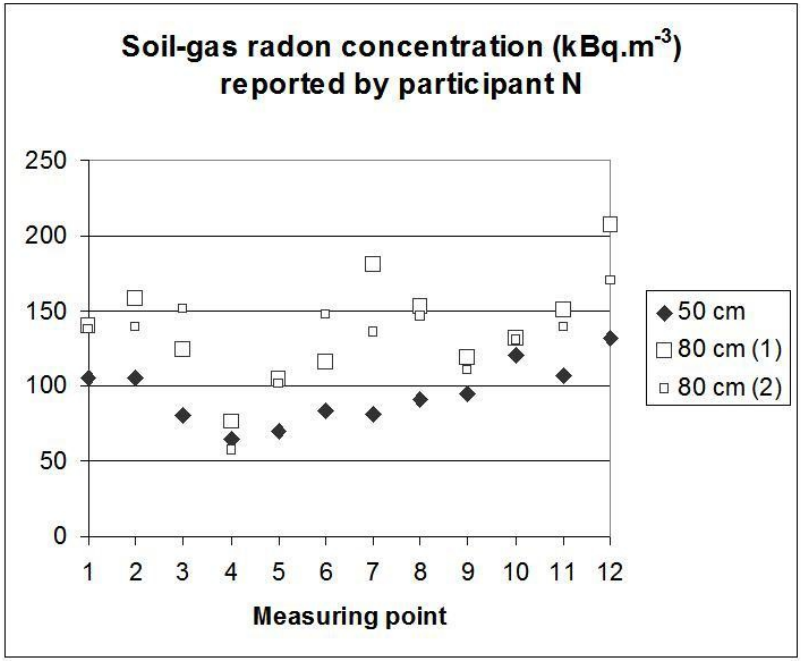


Figure 4. Soil-gas radon concentration data reported by participant N - temporal variations and changes with depth.

Table 8. Results of repeated measurements of soil-gas radon concentration made by participant N.

Time period	Number of meas.	Sampling depths (m)	Soil-gas radon concentration (kBq.m^{-3})					
			min.	max.	median	mean	SD	SD/mean
15:26 - 16:29	12	0.5	64.5	132	93.3	94.9	20.0	0.21
15:28 - 16:34	12	0.8	76.0	207	136	139	34.9	0.25
17:27 - 17:45	12	0.8	57.3	171	139	131	29.4	0.22

Buk (near Pribram), Czech Republic, 2002

Results – spatial variability:

Table 9. Spatial variability of soil-gas radon concentration - analysis of measurements that were made by different participants near to each of 12 reference points.

Reference point	Number of meas.	Soil-gas radon concentration ($kBq.m^{-3}$) min.	max.	median	mean	SD	SD/mean
1	6	109	195	141	151	32.4	0.21
2	6	85.0	266	140	152	61.0	0.40
3	9	70.0	274	138	146	61.2	0.42
4	5	57.0	131	76.0	90.8	32.6	0.36
5	6	101	251	131	145	55.5	0.38
6	9	85.0	238	125	148	52.5	0.36
7	7	70.0	181	124	119	36.0	0.30
8	6	70.0	190	133	132	40.8	0.31
9	6	111	207	123	145	40.8	0.28
10	5	121	243	131	150	52.0	0.35
11	6	114	171	134	138	20.4	0.15
12	6	87.0	207	174	158	46.7	0.30

⇒ *lower values in the surroundings of point No. 4*

Total variability described by the SD/mean ratio: 0.33

Some problems with primary calibration cannot be excluded.

EXPERIENCES (INTERCOMPARISONS 1991 – 2002):

⇨ **From the metrological point of view, there are many serious problems connected with organizing any field intercomparison measurement of soil-gas radon concentration and similar parameters. The natural geological environment is almost never homogeneous. Measured parameters may vary, often very greatly, over a small distance.**

⇨ **Comparison based of single values is almost worthless. Every participant should report a set of measured values.**

⇨ **All participants should measure the soil-gas radon concentration at the same depth below the ground surface.**

⇨ **Geological conditions in a depth of soil-gas sampling as well as conditions on the soil surface should be as homogeneous as possible at the test site.**

EXPERIENCES (INTERCOMPARISONS 1991 – 2002):

⇨ **„Classical“ field intercomparison measurements are not intended to be used as an intercalibration of methods and instruments. Measured values are not reported against a standard or reference measurement. Participants results are compared to each other, in order to obtain an indication of the collective precision of various measurements.**

⇨ **Incidence of outsider values may strongly influnce the results of the intercomparison measurement.**

⇨ **Differences connected with primary calibration are usually lower than 10 percent.**

⇨ **Differences on the level of about 20% seem to be a realistic target for intercomparison measurements of soil-gas radon concentration. If the variability is much larger than 20%, problems with soil-gas sampling and/or with primary calibration are indicated.**

EXPERIENCES (INTERCOMPARISONS 1991 – 2002):

⇨ **Frequent systematic failures are connected with soil-gas sampling.** **If the sampling system is not sealed perfectly, the soil-gas samples are „contaminated“ by the atmospheric air. The real soil-gas radon concentrations are then underestimated. For testing the applicability of sampling methods, it is useful to choose a test site characterized by medium, or low permeability of soil.**

⇨ **Preliminary measurements should be limited at a chosen test site to avoid a destruction of the upper soil layers (the upper soil layers should not remind of a Swiss cheese). This is very important if radon exhalation from the ground surface is measured at the same test site.**

SYSTEM OF SOIL-GAS RADON DATA STANDARDIZATION IN THE CZECH REPUBLIC

about 100 institutions (mostly private firms) dealing with the determination of radon index of building sites (= measurement of soil-gas radon concentration and classification of permeability of soil)

each subject

⇨ has to pass the training course „Determination of radon index of building sites“

⇨ has to pass the intercomparison measurement of soil-gas radon concentration at three field radon reference sites

administrator: Charles University in Prague, Faculty of Science; 3 different levels of soil-gas radon concentration

⇨ has to verify regularly all measurement devices for the determination of soil-gas radon concentration in radon chamber

⇨ has to get the authorization from the State Office for Nuclear Safety

The procedure was used in the last soil-gas radon international intercomparison exercise (Czech Republic, 2010).

This approach represents a step from a „classical“ field intercomparison measurement to a standardization.

SYSTEM OF RADON DATA STANDARDIZATION IN THE CZECH REPUBLIC

National radon chamber:
(Located in Příbram)

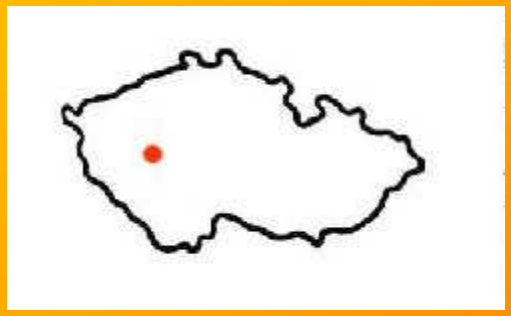
- **Verification of instrument, its function, sensibility and calibration,**
- **Verification of data processing.**

National radon chamber was levelled with PTB Braunschweig, GER

Radon reference sites:
(Located in the central Bohemia)

- **Test of soil gas sampling,**
- **Transfer of soil gas sample and its timing,**
- **Test of the radon instrument and its function,**
- **Elimination of thoron,**
- **Stability of field operation,**
- **Test of correct data processing.**

CHARACTERISTICS OF RADON REFERENCE SITES, CZECH REPUBLIC

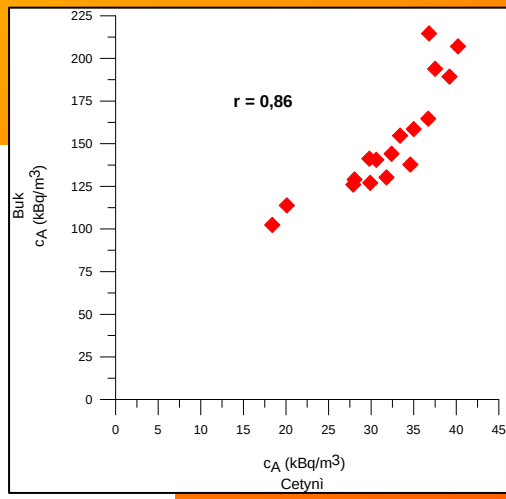


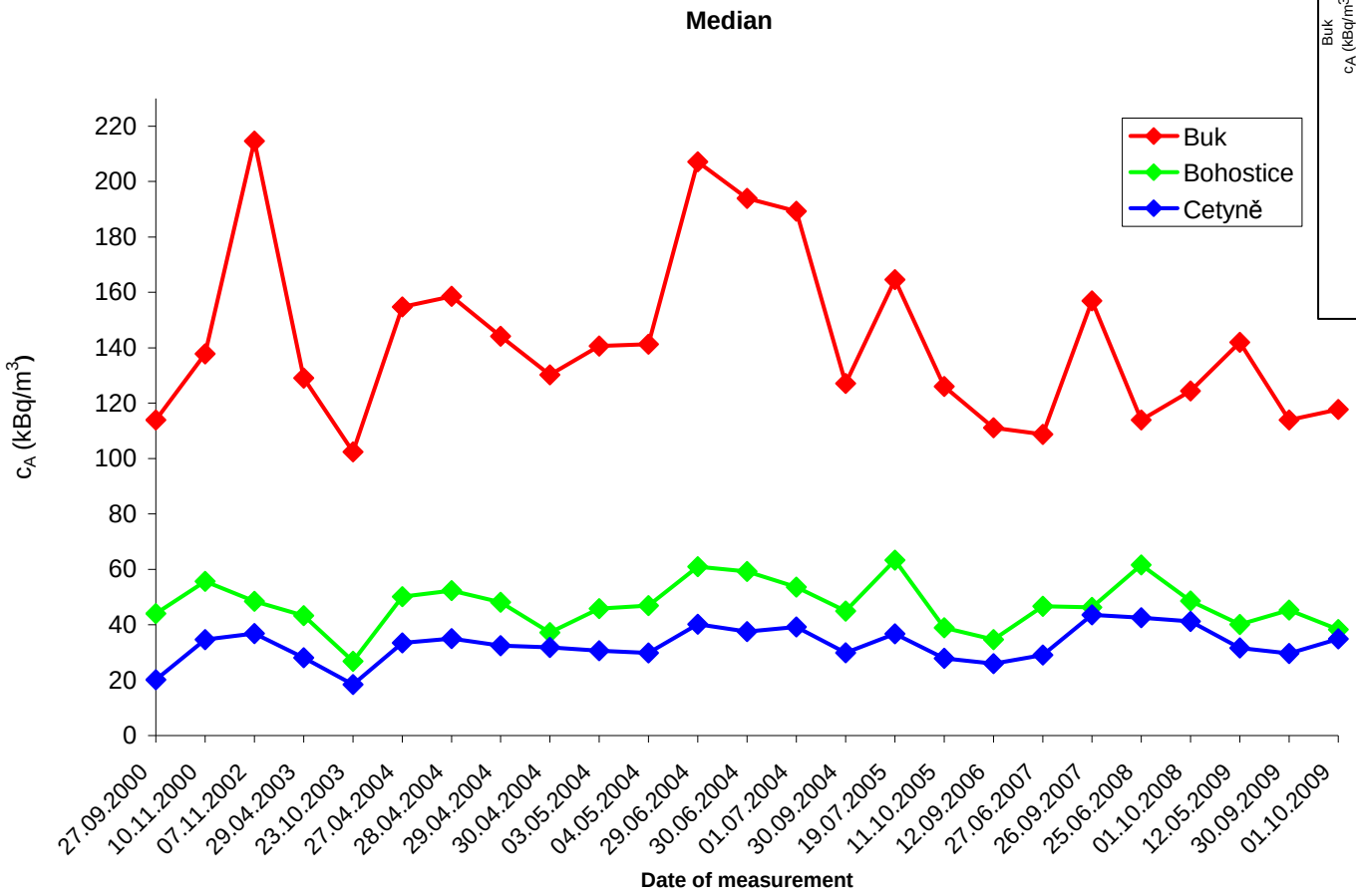
Radon reference sites

Number of stations at each site: 15
Grid of stations: 5x5 m
Distance of the 3 reference sites: 12 km

Reference site	c_A ^{222}Rn (kBq/m^3)	Permeab. of soil	Basement rock	Soil	U (ppm)	Terrain	Access for cars
Cetyne	32	L,(M),H	orthogneiss	SL	2.0	meadow	+
Bohostice	52	(L),(M),H	orthogneiss	LS,CS	2.3	meadow	+
Buk	155	H	granodiorite	LS	3.6	meadow	+

TEMPORAL VARIATIONS OF RADON IN SOIL GAS AT REFERENCE SITES 2000 - 2009





Temporal variations of radon activity concentration in soil gas at reference sites Cetyne, Bohostice and Buk, the Czech Republic.

TESTS AT RADON REFERENCE SITES

Computer programme TestMOAR

Test 1

Comparison with the group

Test 2

Comparison with the group

Charles University in Prague

Charles University in Prague, Faculty of Science
Institute of Hydrogeology, Engineering Geology and Applied Geophysics
Department of Applied Geophysics
128 43 Praha 2, Albertov 6

Assessment of comparison measurement of Rn-222 activity concentration in soil air at reference sites Cetyně, Bohostice and Buk.

Organization: AAA
Street and No.
City/village, postal code

Date of measurement: 10. September 2000

Used symbols: c_A - radon activity concentration in soil air, (kBq/m^3)
t - argument of Student´s distribution

Test 1 - test of differences in c_A measured by organizations at single reference sites

The difference between c_A measured by given organization at single observation points of a reference site and median of c_A data determined by other organizations, including the administrator, at relevant observation points, in the same day, is tested. The difference is significant, if the calculated interval of confidence does not imply zero.

Reference site	*Interval of confidence*	*Ratio of data outside the interval of confidence*
Cetyně	< -5.963; 11.449 >	4/15
Bohostice	< -11.165; 4.912 >	1/15
Buk	< -1.541; 9.701 >	2/15

Test 2 - linear regression and correlation of c_A data measured in the same day at reference sites

Dependence of c_A data measured by given organization (y) on medians (x) of c_A data determined by other organizations, including the administrator, at relevant observations points, in the same day, is expressed by linear regression $y = a + bx$. In ideal case of data coincidence is $a = 0$, $b = 1$. The data acceptable coincidence is not proved, if the calculated t-value of the test criterion exceeds the critical t-value.

Regression parameter	*Calculated t-value*	*Critical t-value*	*Coefficient of correlation*
a = -0.486	0.181	2.695	0.984
b = 1.022	0.788	2.695	

TESTS AT RADON REFERENCE SITES

Test 3

Comparison with the radon database

Testing criterion R1/R2 of an ideal value equal to one and acceptable deviations +/- 30 %; R1/R2 <0.7 – 1.3>

Test 3 - comparison of c_A data of an organization with all available c_A data from the reference site, under elimination of radon temporal variations and the level of c_A data of the administrator

Radon activity concentration in soil air at each single reference site is tested by means of a ratio of two parameters R1 and R2. Parameter R1 is the ratio of the c_A mean at the reference site, reported by the organization, to c_A mean, reported by the administrator. Parameter R2 is the average of all available R1 data of preceding measurements at the given reference site. Testing criterion R1/R2 compares the c_A data, reported by the organization, with c_A data of preceding measurements of all organizations. Acceptable deviation from ideal value R1/R2 = 1 is 30 % relatively, R1/R2 < 0.7; 1.3 >.

Reference site	*Parameter R1*	*Ratio R1/R2*
Cetyně	1.050	1.084
Bohostice	0.865	0.917
Buk	0.993	1.018

Ideal value is 1.000

Conclusions

Test 1 and test 2 (both orientative) indicate general coincidence between radon concentration activity reported by your organization and the data reported by organizations participating in the test on the same day. Test 3 shows an agreement of your data with the data of all organizations tested at the reference sites since the year 2000. The procedure of radon in soil air determination, applied by your organization, can be used for radon risk mapping at building sites after the Act No. 18/2002, and the relevant Decree of the State Office for Nuclear Safety No. 184.

Datum

Signature

Seal

SOIL-GAS RADON INTERCOMPARISON MEASUREMENT, CZECH REPUBLIC, 2010

(RIM 2010)

Buk, Cetyne, Bohostice, 20 and 21-09-2010

RIM 2010

Final report not yet published.

All participants have already obtained the above mentioned protocol from the administrator of Czech reference sites (Charles University in Prague).

RIM 2010

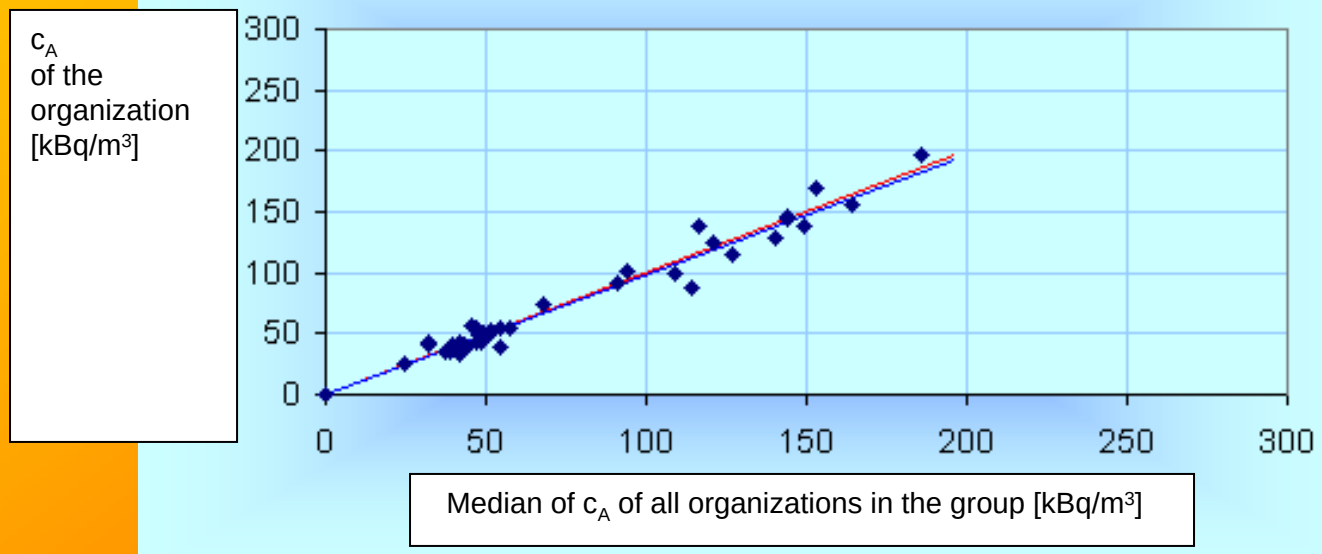
Results - example

Test No. 2: Linear regression y = a + bx of radon activity concentration reported by an organization (y) at a single station and median (x) of radon activity concentration of the group of organizations at the same station. An ideal data agreement is a = 0, and b = 1. This presumption is rejected if computed t-value is larger than critical t-value. Level of significance α = 1 %.

Tested by Computer programme TestMOAR.

Example of excellent agreement between radon data of an organization and medians of radon data of the group of organizations.

Test 2 – linear regression y = a + bx (blue) between radon activity concentration c_A reported by the organization (y) and medians of c_A (x) of all organizations in the group. Ideal regression line (a = 0, b = 1) is marked red.



a	=	0,599	ta	=	0,236
b	=	0,984	tb	=	0,542
r	=	0,982	tkrit	=	**2,695**

RIM 2010

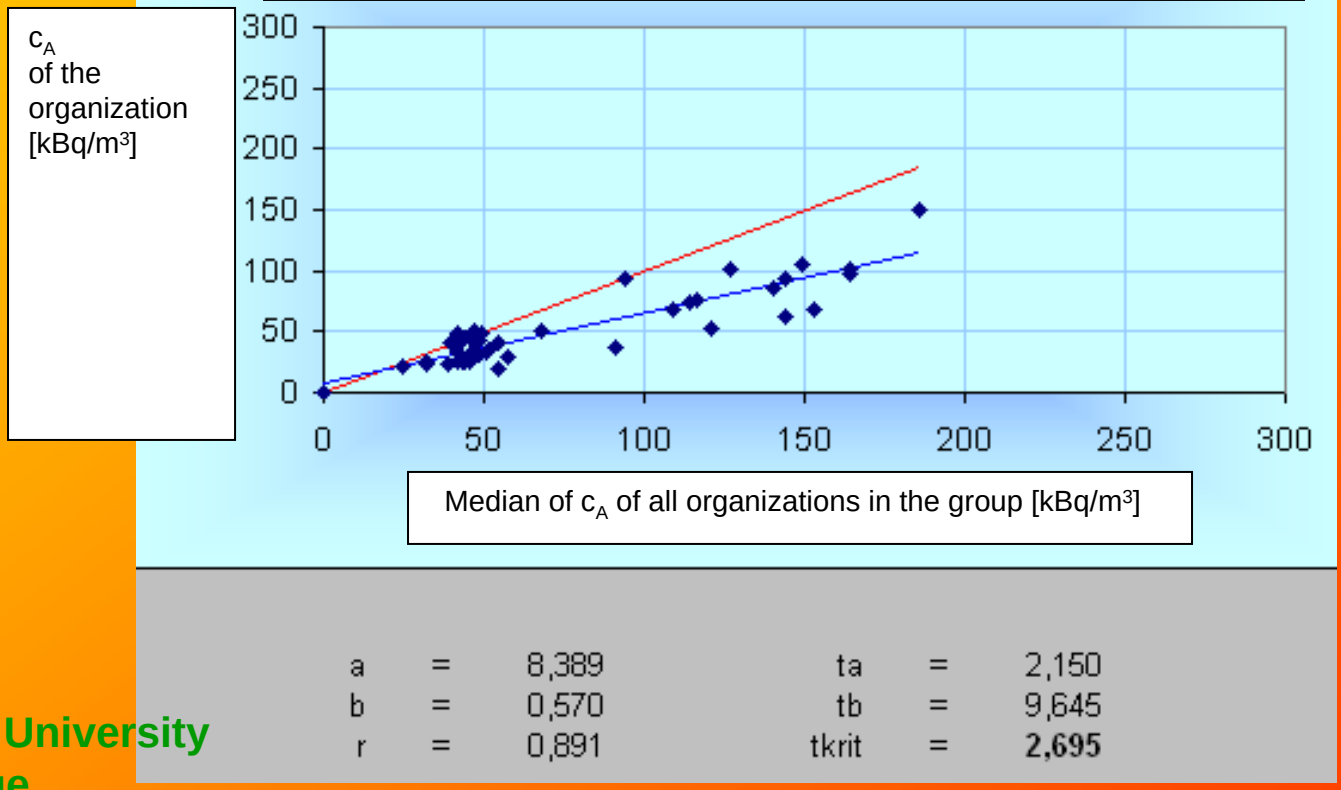
Results - example

Test No. 2: Linear regression y = a + bx of radon activity concentration reported by an organization (y) at a single station and median (x) of radon activity concentration of the group of organizations at the same station. An ideal data agreement is a = 0, and b = 1. This presumption is rejected if computed t-value is larger than critical t-value. Level of significance α = 1 %.

Tested by Computer programme TestMOAR.

Example of poor agreement between radon data of an organization and medians of radon data of the group of organizations.

Test 2 – linear regression y = a + bx (blue) between radon activity concentration c_A reported by the organization (y) and medians of c_A (x) of all organizations in the group. Ideal regression line (a = 0, b = 1) is marked red.



a	=	8,389	ta	=	2,150
b	=	0,570	tb	=	9,645
r	=	0,891	tkrit	=	**2,695**

RIM 2010

Results - example

Test No. 3: Comparison of average (AM) radon activity concentration in soil gas at radon reference sites

Normed radon data R1/R2
Criterion R1/R2 ideal value 1.0, acceptable range (0.7; 1.3)
Criterion R1/R2 is applicable for each single reference site

Tested by Computer programme TestMOAR

	Reference site			
	Cetyne	Bohostice	Buk	
Organization	Criterion R1/R2			Average R1/R2
A02	1,135	1,075	1,015	1,075
A03	1,108	1,041	1,275	1,141
A04	1,055	1,021	1,094	1,057
A05	0,795	0,725	0,722	0,747
A06	1,230		0,990	1,110
A07	0,834	0,688	0,662	0,728
A08	1,162	1,023	1,410	1,198
A09	1,094	0,872	1,072	1,013
A10	0,960	0,990	1,041	0,997
A11	0,986		1,021	1,004
A12	1,026	0,970	1,012	1,003
A13	1,482		1,360	1,421

Thank you