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RELIABILITY AND DEVIATIONS IN ESTIMATES OF RADON IN SOIL GAS

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PARAMETERS AFFECTING RELIABILITY OF ESTIMATES OF RADON ACTIVITY CONCENTRATION IN SOIL GAS

- “ Radon instruments and their calibration**
- “ Homogeneity of geological basement and the number of measured field stations**
- “ Random character of lay out of measured field stations**
- “ Depth and the way of soil gas sampling**
- “ Method and exposure time of radon measurement**
- “ Choice of a statistical parameter characterizing the set of field radon data**
- “ Temporal variation of radon activity concentration in soil gas**

VARIOUS INSTRUMENTS AND TECHNIQUES OF RADON ANALYSES

Ionization chamber



Lucas chambers



**Soil gas sample
transferred into liquid**



Continuous sampling



RADON DATA STANDARDIZATION IN THE CZECH REPUBLIC

- * **National radon chamber:**
(Located in Pribram)



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

(National radon chamber was levelled with PTB Braunschweig, BRD)

- * **Radon reference sites:**
(Located in the Central Bohemia)

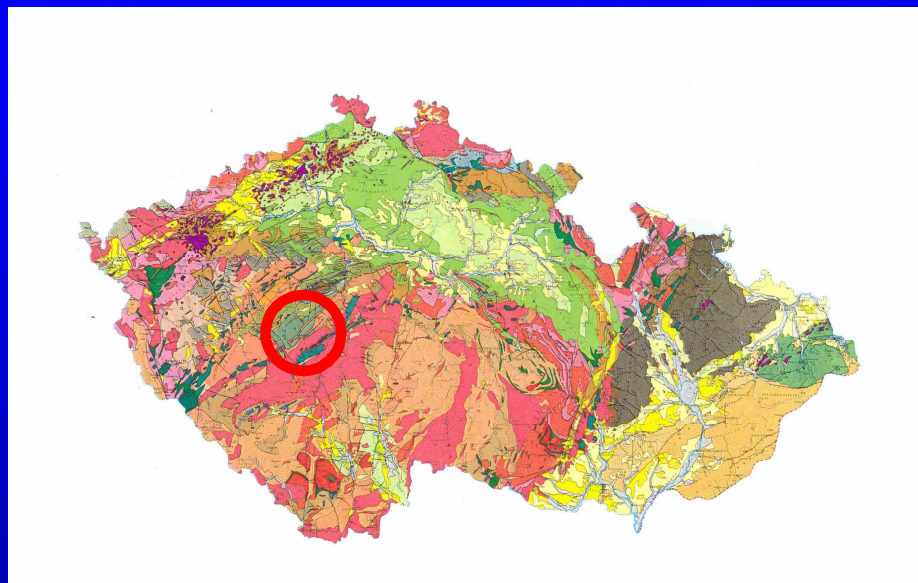


- ı Test of soil gas sampling,
- ı Transfer of soil gas sample and its timing,
- ı Test of the radon instrument and its function,
- ı Test of correct data processing,
- ı Elimination of thoron,
- ı Stability of field operation.

RADON REFERENCE SITES IN THE CZECH REPUBLIC

- “ Radon reference sites have been used since 1992.
- “ Three New radon reference sites, established in 2000 , are located in central Bohemia near to the city Píbram. By 2014, 233 organization tested their radon measurements at radon reference sites.

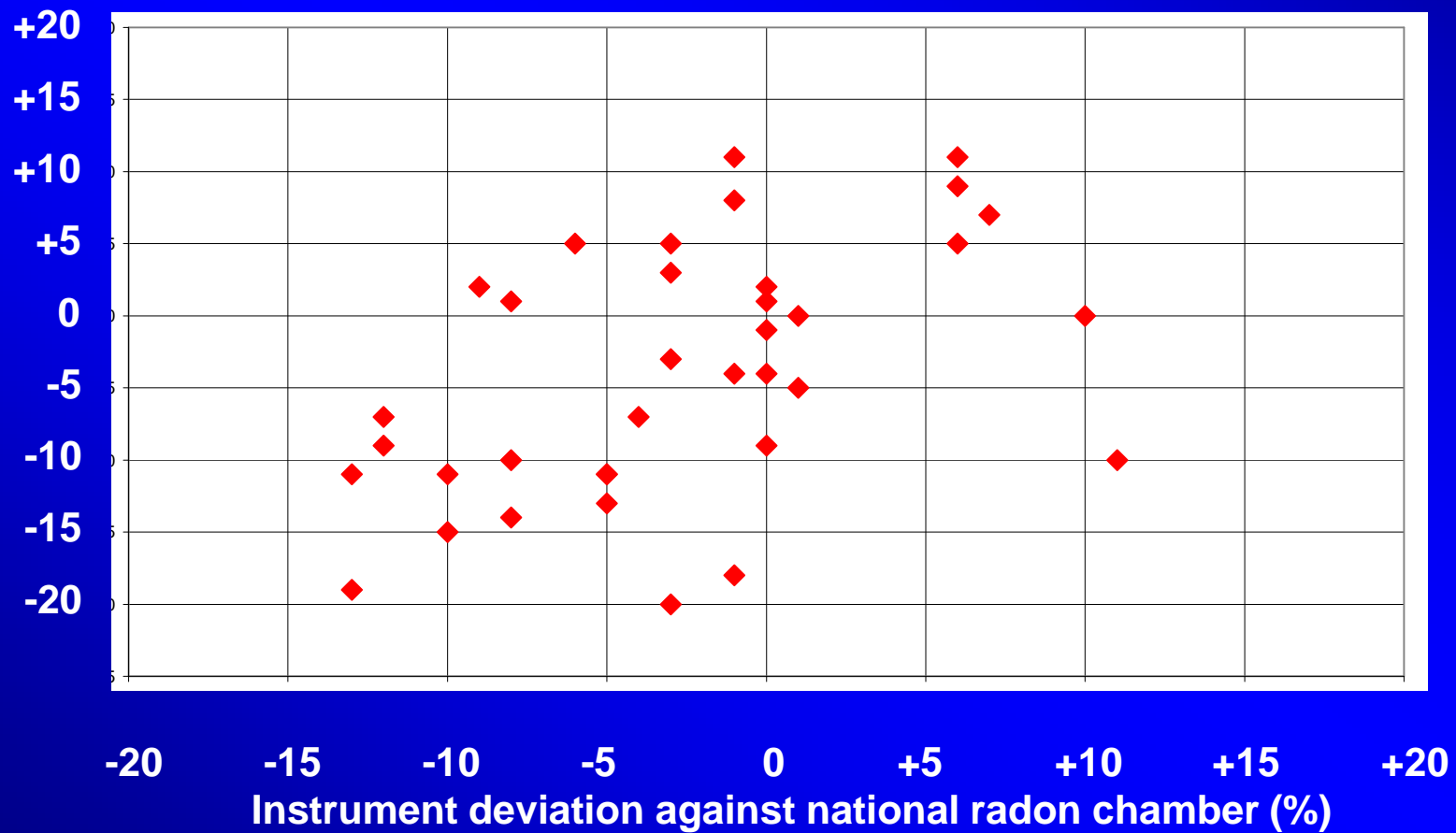
Radon reference sites in Píbram area



Geological map of the Czech Republic

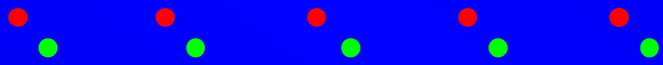
INSTRUMENT CALIBRATION AND ITS VERIFICATION AT RADON REFERENCE SITES

Deviation against the database of radon reference sites

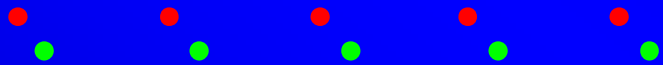


Reliability of Radon Measurement

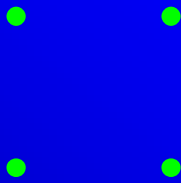
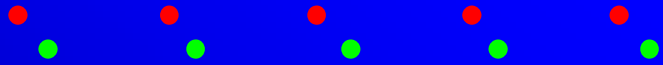
RANDOM CHOICE OF MEASURED STATIONS AND NUMBER OF MEASURED STATIONS



Random choice of location
of field stations



Number of field stations 15

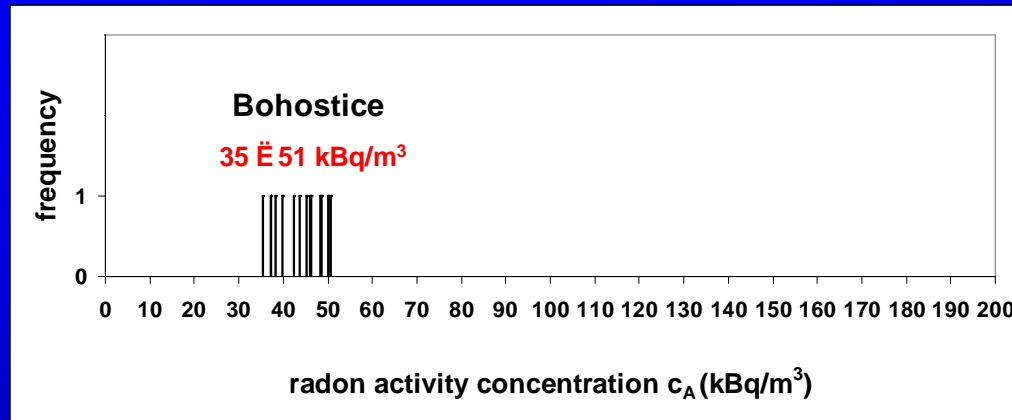


Number of field stations 4

Geological environment is not homogeneous

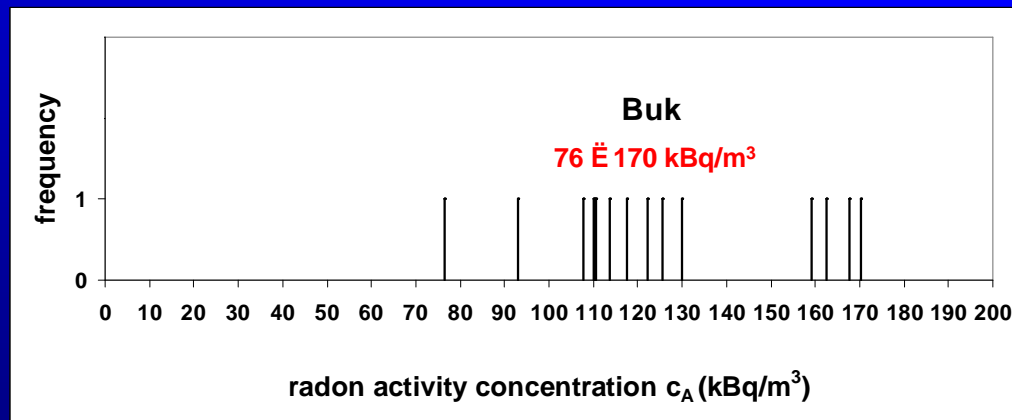
**RANDOM CHOICE OF POINTS FOR SOIL GAS
SAMPLING WAS TESTED AT TWO RADON
REFERENCE SITES WITH DIFFERENT
DISTRIBUTION OF RADON ACTIVITY
CONCENTRATION**

DISTRIBUTION OF RADON IN SOIL GAS AT RADON REFERENCE SITES BOHOSTICE AND BUK



Radon reference site Bohostice (orthogneiss)

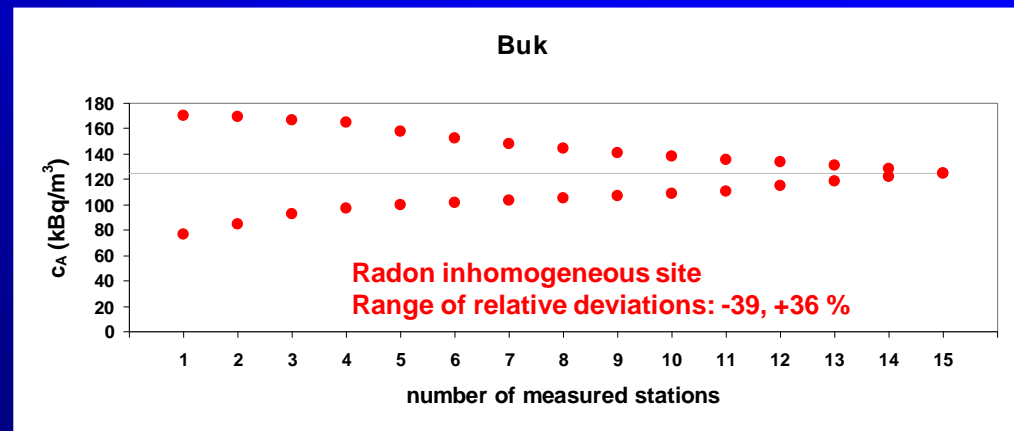
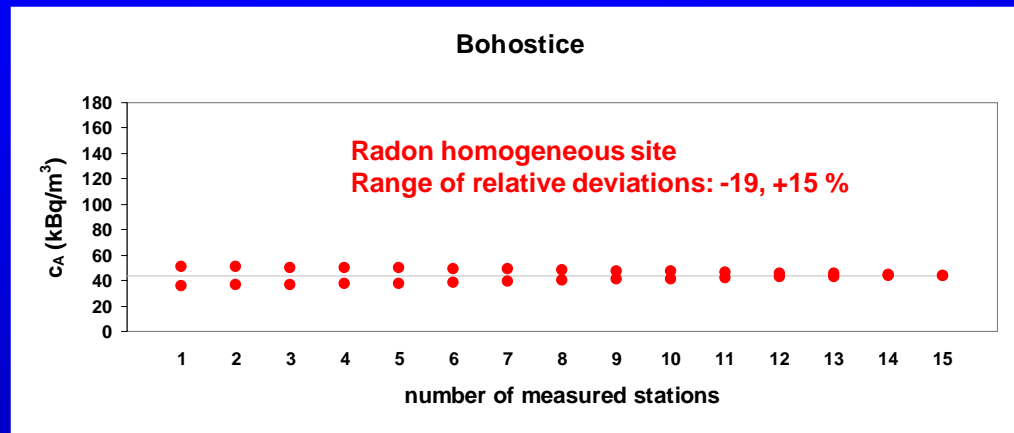
15 stations in area of 20 x 10 m.
Radon reference site with low radon dispersion



Radon reference site Buk (granodiorite)

15 stations in area of 20 x 10 m.
Radon reference site with high radon dispersion

MAGNITUDE OF EXTREME POSSIBLE ERRORS OF RADON ESTIMATES IN DEPENDENCE ON THE NUMBER OF MEASURED STATIONS



Radon reference sites
Bohostice and Buk

15 stations on each reference site

- Mean radon activity concentration computed from N extreme high or low radon data from N = 15 radon data set

- Defines the zone of possible errors of radon estimates if resultant radon value for a site is determined from N < 15 measurements

MAGNITUDE OF EXTREME POSSIBLE ERRORS OF RADON ESTIMATES IN DEPENDENCE ON THE NUMBER, N, OF MEASURED STATIONS

N	Radon reference site Bohostice		Radon reference site Buk	
	- deviation %	+ deviation %	- deviation %	+ deviation %
1	19.4	15.1	38.9	36.1
2	17.5	14.7	32.3	35.0
3	16.7	14.5	26.1	33.3
4	15.8	13.5	22.6	31.8
5	14.5	12.8	20.4	26.2
6	12.7	11.5	18.9	21.9
7	11.0	10.5	17.5	18.5
8	9.2	9.6	16.1	15.4
9	7.7	8.5	14.6	12.7
10	6.4	7.2	13.1	10.3
11	4.9	5.7	11.5	8.3
12	3.6	4.2	8.3	6.6
13	2.3	2.7	5.3	5.0
14	1.1	1.4	2.5	2.8
15	0.0	0.0	0.0	0.0

THE NUMBER OF OBSERVED STATIONS AT A BUILDING SITE

- “ **Geological environment is not homogeneous.** Radon activity concentration in soil gas exhibits lateral and vertical variations.
- “ **Radon index of a building site must be determined on the basis of a radon data set.**
- “ Various **statistical parameters** of radon data set are used as characteristic. In the Czech Republic, **the third quartile** is used for building site specification.
- “ **Minimal number of measured field stations is 15 in the Czech Republic.**

**TESTS OF RANDOM LAY OUT OF MEASURED FIELD
STATIONS**

DEVIATIONS OF RADON ACTIVITY CONCENTRATION IN SOIL GAS DUE TO RANDOM LAY OUT OF STATIONS

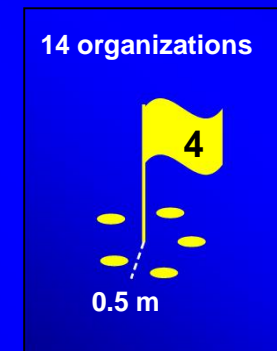
Number of participating organizations: 14

Number of measured fixed stations: 4

Random choice of points of measurement in circle area of 1 m diameter
around fixed station

Different measurement techniques

Reference site	Mean radon deviation	Relative deviation
Cetyne (32 kBq/m ³)	7.3 kBq/m ³	22 %
Bohostice (52 kBq/m ³)	6.2 kBq/m ³	11 %
	7.8 kBq/m ³	14 %
Buk (155 kBq/m ³)	20.7 kBq/m ³	12.8 %



DEVIATIONS OF RADON ACTIVITY CONCENTRATION IN SOIL GAS DUE TO RANDOM LAY OUT OF STATIONS

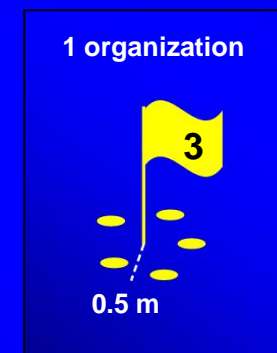
Number of participating organizations: 1

Number of measured fixed stations: 3

Random choice of points of measurement in circle area of 1 m diameter
around fixed station

Uniform measurement technique

Reference site	Mean radon deviation	Relative deviation
Cetyne (32 kBq/m ³)	2.2 kBq/m ³	8.1 %
Bohostice (52 kBq/m ³)	5.7 kBq/m ³	12.5 %
Buk (155 kBq/m ³)	16.4 kBq/m ³	9.8 %



DEVIATIONS OF RADON ACTIVITY CONCENTRATION IN SOIL GAS DUE TO COUNTING STATISTICS AND INSTABILITY OF SOIL GAS SAMPLING

Number of participating organizations: 1

Number of measured fixed stations: 3

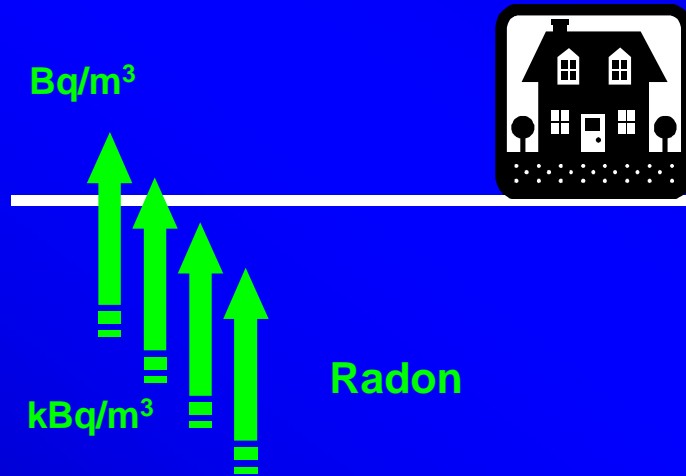
Soil gas sampling from one fixed hollow rod

10 repeated measurements with uniform measurement technique

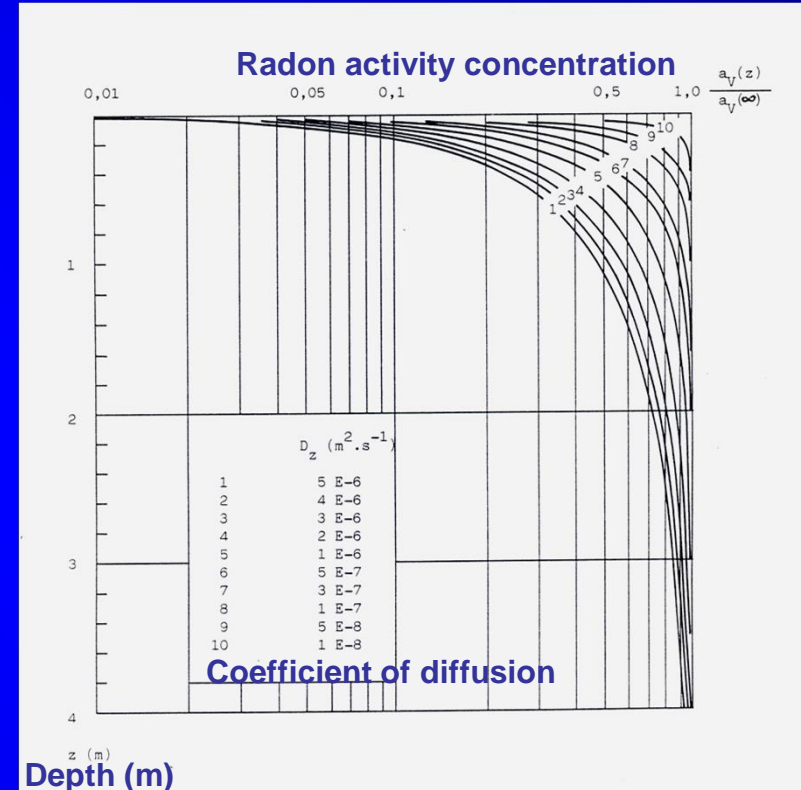
Reference site	Mean radon deviation	Relative deviation
Cetyn (32 kBq/m ³)	2.01 kBq/m ³	7.6 %
Bohostice (52 kBq/m ³)	3.57 kBq/m ³	6.7 %
Buk (155 kBq/m ³)	3.94 kBq/m ³	2.8 %



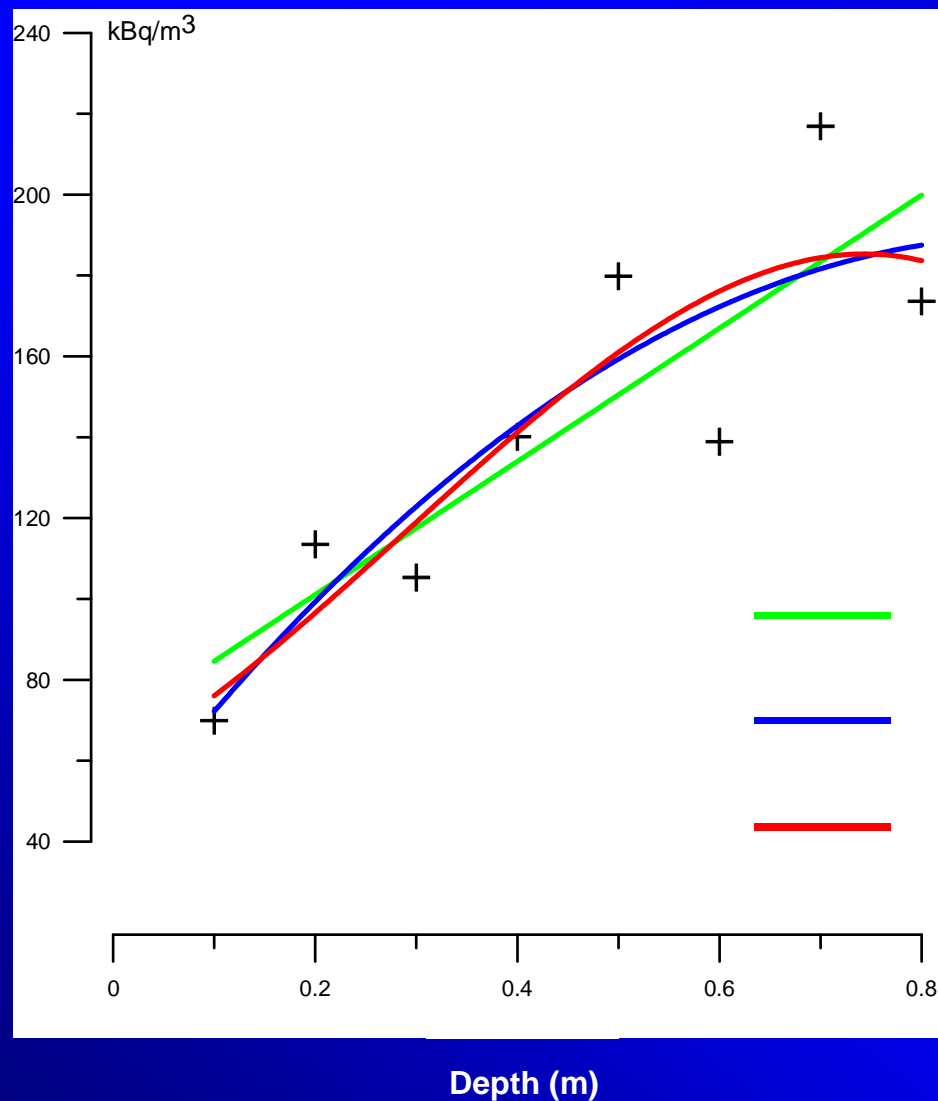
VERTICAL CHANGE OF RADON ACTIVITY CONCENTRATION CLOSE TO THE EARTH'S SURFACE



Vertical gradient of radon activity concentration is relatively high close to the Earth's surface, especially in highly permeable soils.



INCREASE OF RADON ACTIVITY CONCENTRATION WITH DEPTH



Experimental data on the increase of radon activity concentration with depth at the radon reference site Buk of good soil permeability

Regression of

the first grade

the second grade

the third grade

RELATIVE ERRORS, E %, IN DETERMINATION OF RADON IN SOIL GAS DUE TO RADIATION COUNTING STATISTICS AND EFFECT OF THORON IN SOIL GAS

Theoretical data

t = 0 (transfer of a soil gas sample into the detection chamber)

Measurement interval min	c _A (²²² Rn) kBq/m ³ c _A (²²⁰ Rn) kBq/m ³	10	20	50	50	50	100
		10 E (%)	20 E (%)	25 E (%)	50 E (%)	75 E (%)	75 E (%)
0 . 1		26.5	18.3	9.2	11.4	13.3	7.3
1 . 2		19.0	13.0	7.0	8.0	9.0	5.3
2 . 3		15.4	10.4	5.9	6.4	6.9	4.3
5 . 6		12.1	8.1	4.9	5.0	5.0	3.5
10 . 11		10.9	7.4	4.5	4.5	4.5	3.2
15 . 16		10.4	7.0	4.3	4.3	4.3	3.0
60 . 61		9.0	6.2	3.8	3.8	3.8	2.7
180 . 181		8.8	6.0	3.7	3.7	3.7	2.6
0 . 3	Measurement 3x1 min	19.0	12.9	7.2	7.9	8.6	5.3

Radon
Thoron

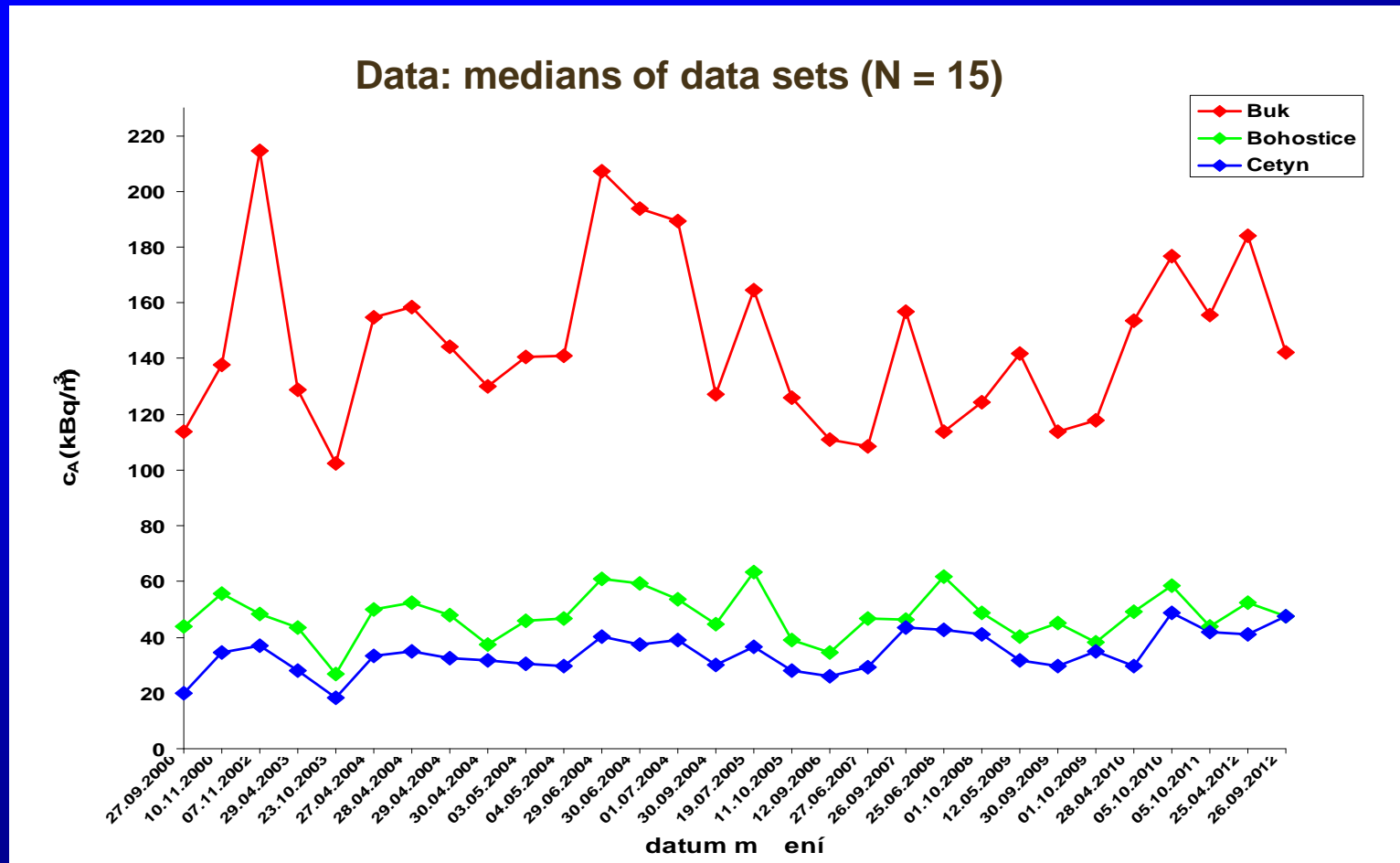


Effect of thoron alpha radiation



Effect of count rate level and counting statistics

TEMPORAL VARIATION OF RADON ACTIVITY CONCENTRATION IN SOIL GAS AT RADON REFERENCE SITES 2000 - 2012



Experimental data on radon activity concentration in soil gas measured by Charles University in Prague, Faculty of Science, Department of Applied Geophysics, at 15 fixed stations of radon reference sites in the Czech Republic

TEMPORAL VARIATION OF RADON ACTIVITY CONCENTRATION IN SOIL GAS AT RADON REFERENCE SITES 2000 - 2012

	Cetyne	Bohostice Median	Buk	Cetyne	Bohostice Arithmetical mean	Buk
AM (N= 30)	34,3	47,7	145,9	36,9	47,4	148,3
SD	7,1	8,2	29,5	6,9	7,2	25,5
V (%)	20,9	17,2	20,2	18,7	15,2	17,2
min	18,4	26,8	102,4	21,0	28,9	103,9
max	48,7	63,3	214,6	54,2	60,2	200,1
max/min	2,7	2,4	2,1	2,6	2,1	1,9

CONCLUSIONS

- “ Requirement on instrument radon sensitivity: 1 kBq/m³.
- “ Random choice of points for soil gas sampling yields deviations in radon estimates up to +/- 20 %.
- “ Fixed depth of soil gas sampling limits errors due to vertical gradient of radon activity concentration.
- “ Characteristics of radon at a building site must be determined as statistical parameter from sufficient number of field measurements.
- “ Temporal variations of radon in soil gas add additional deviation to radon level estimate.
- “ Uncertainty in soil gas radon estimates should be considered in assessment of radon risk of building sites.



**Radon reference site
Buk**