11th INTERNATIONAL WORKSHOP
on the GEOLOGICAL ASPECTS OF RADON RISK MAPPING
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THE PROBLEMS OF DETERMINING ANNUAL EFFECTIVE DOSE DUE TO RADON INHALATION

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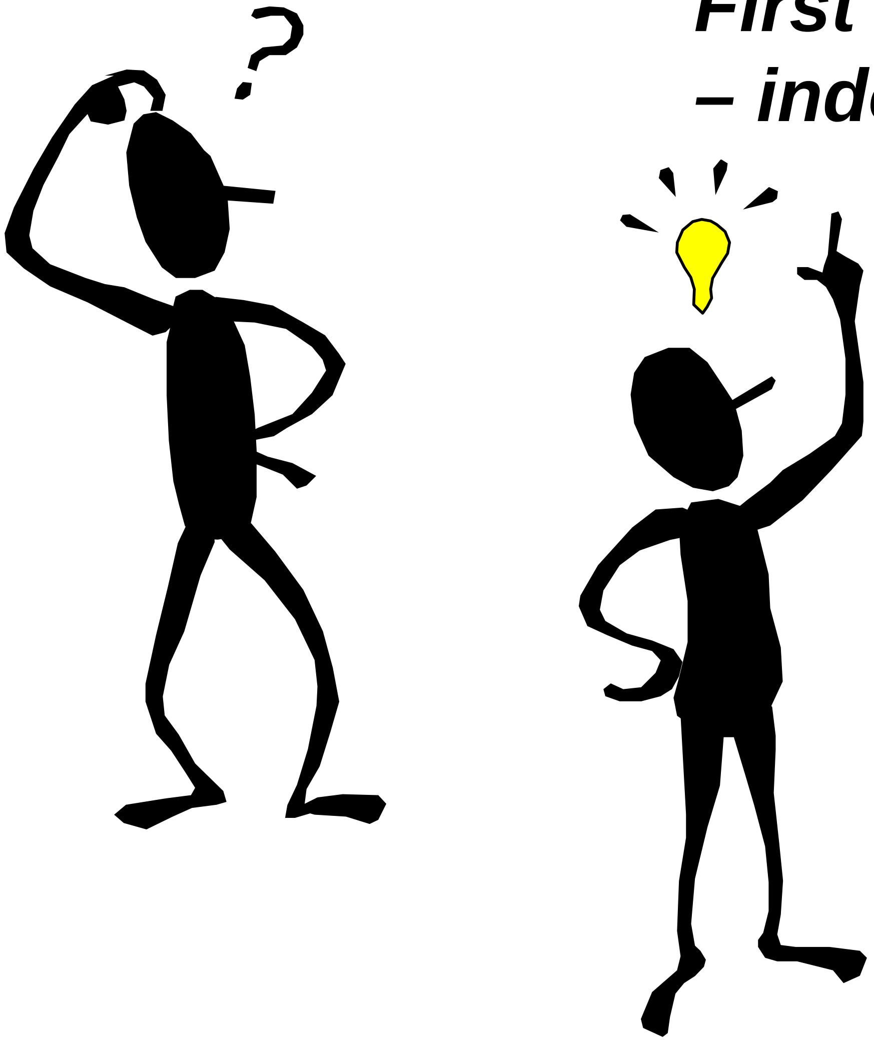
KRAKÓW, POLAND

FIRST QUESTION

First task:
– indoor radon concentration



Results
- as true as possible

precise and proper interpretation of obtained measurement results

IDEA OF MEASUREMENTS

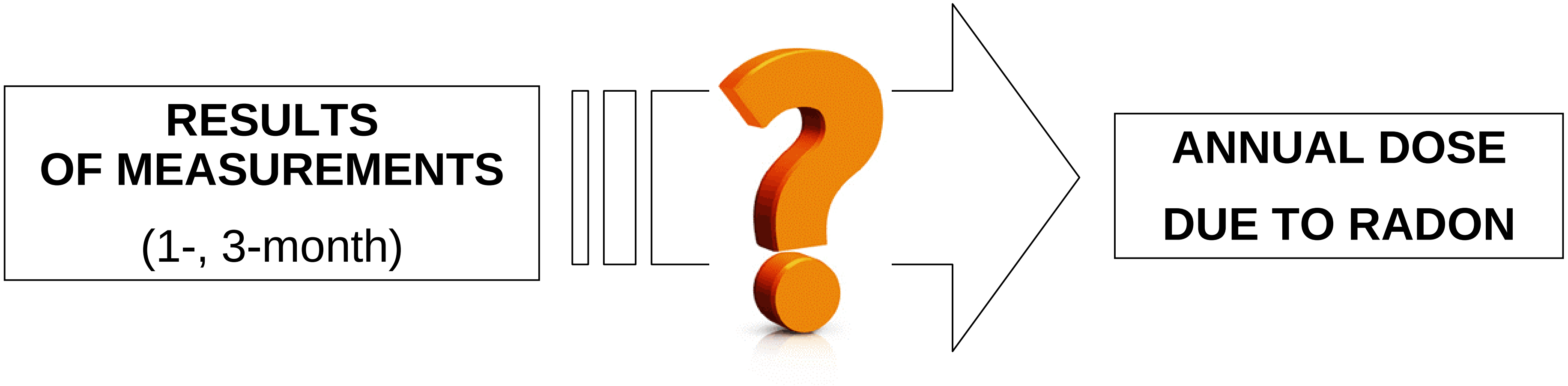
Indoor radon concentration is variable, subject to: diurnal and seasonal fluctuations.

There are many parameters influencing radon changeability such as:

- **location of the building,**
- **occupant behaviour,**
- **ventilation of the room,**
- **pressure gradient,**
- **outdoor-indoor temperature difference,**
- **wind speed and direction,**
- **etc.**

ANNUAL DOSE FROM RADON

As far as radiological protection is concerned it is important to determine the mean annual radon concentration of an individual building

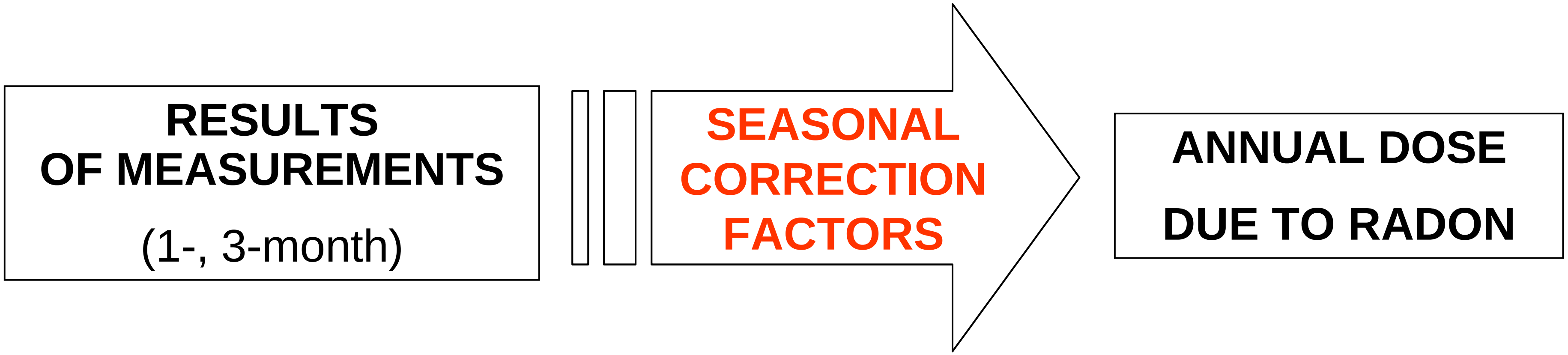


In fact, the performance of a long– term measurement for a period of a year is unpractical and inconvenient.

The exposures of track detectors usually last a month or 3 months at the most and hence one has to evaluate the radiation hazard due to radon inhalation on the basis of monthly or quarterly results.

ANNUAL DOSE FROM RADON

As far as radiological protection is concerned it is important to determine the mean annual radon concentration of an individual building



The calculation of the mean annual radon activity concentration

from the above values

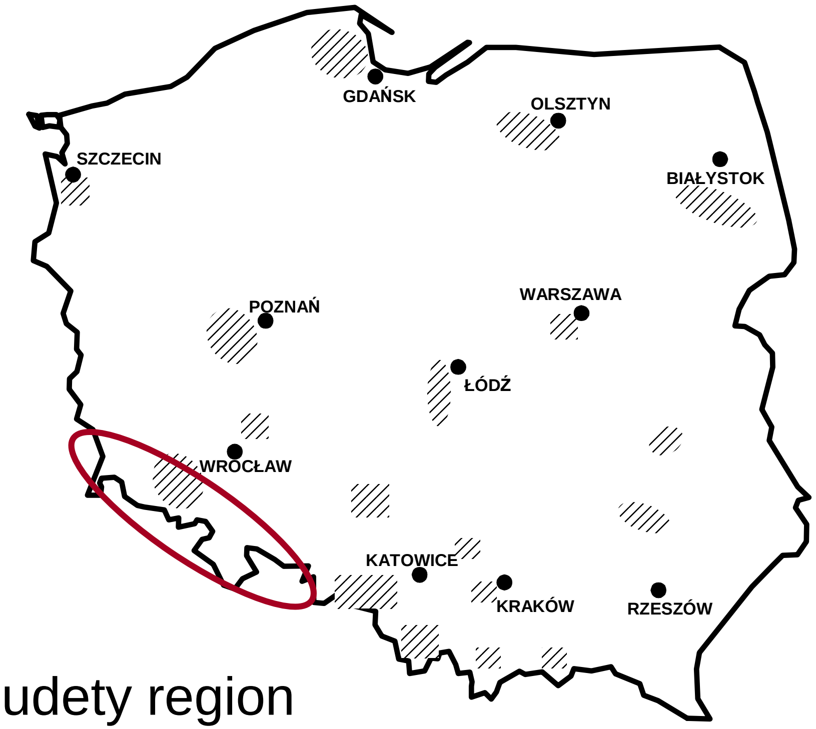
is only possible if one knows

the SEASONAL CORRECTION FACTORS.

RADON MEASUREMENTS

The total number of measurements on Rn-222 activity concentration yielded:

1 554 mean monthly values and 417 mean quarterly values in 132 buildings in Poland



Sudety region
radon prone area

- one year time of measurements
- ground floor (rooms, kitchen)
- apartments in normal use
- typical building materials (hollow blocks, slag concrete)
- detectors placed in the middle of a room, not close to windows, doors

RADON MEASUREMENTS

The total number of measurements on Rn-222
activity concentration yielded:

1 554 mean monthly values and 417 mean quarterly values
in 132 buildings in Poland

For each building, i.e. for each measurement point,
the following information (using protocol) was collected:

- type of a building (detached, terraced, tenement, block of flats),
- building materials used for wall construction,
- a type of a cellar,
- building materials used for wall finishing
- geographical location (GPS coordinates).

TYPES OF HOUSES in POLAND


terraced

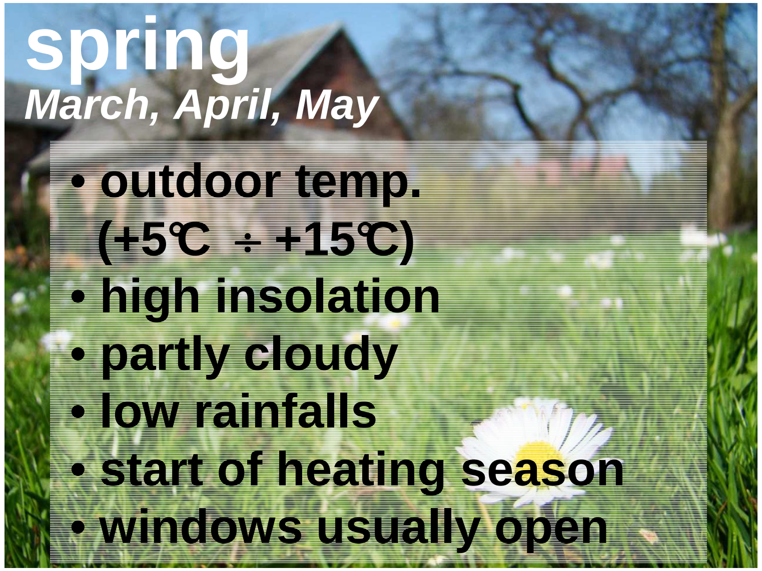

detached house

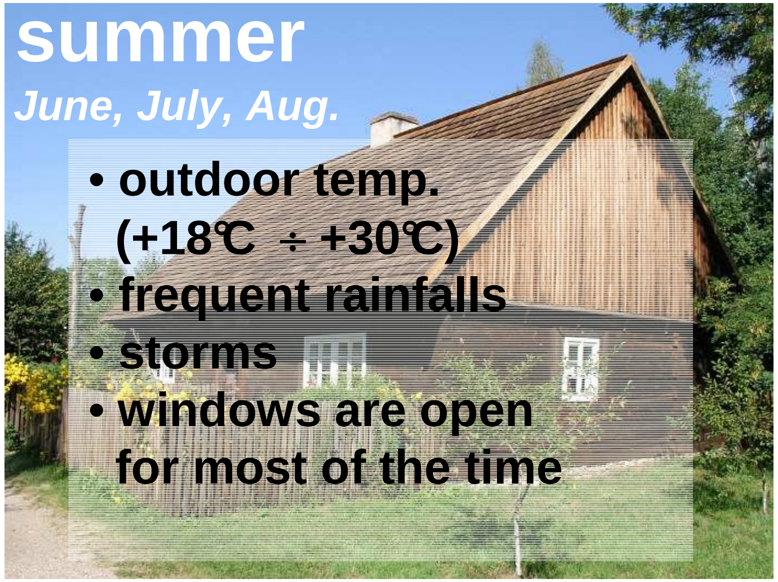

tenement

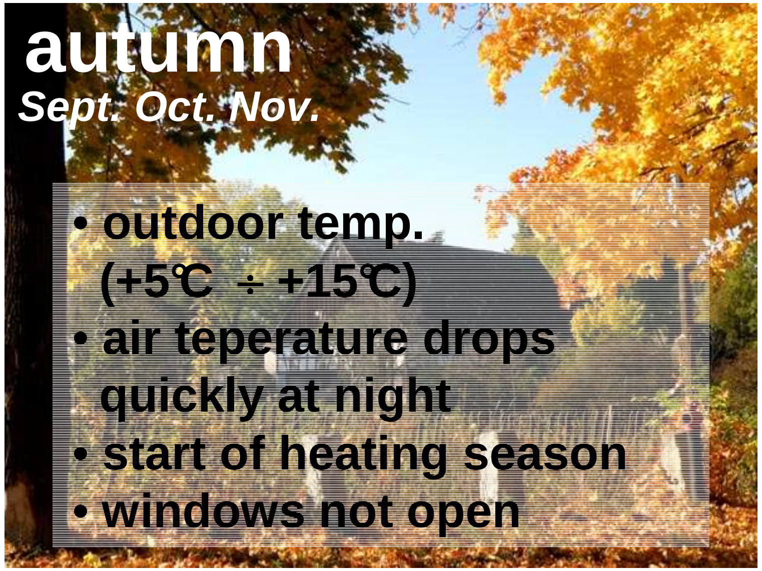

block of flats

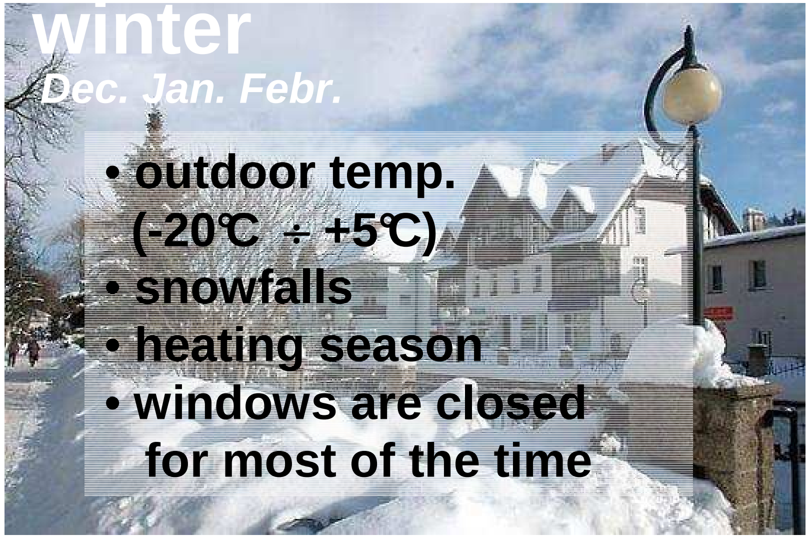
WEATHER CONDITIONS IN POLAND

WEATHER CONDITIONS IN POLAND



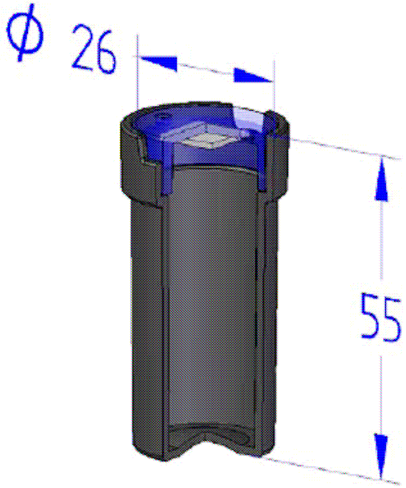






DETECTORS & READING

DETECTORS: diffusion chamber with CR-39 type track detectors



RadoBath

- 25% NaOH (sodium hydroxide solution)
- Etching temp.: 90℃
- Etching time: 4.5 h
- Set: 432 det.

THE RADOSYS SYSTEM 2003

AUTOMATIC READING of CR-39 det.

- B&W CCD Camera
- magnification: 100 x
- 12 detectors; 60 s /1 detector
- Resolution > 150 tracts / mm^2
- Scanning area:: 47 mm^2
- SQL database engine (PostgreSQL)

STEPS of MEASUREMENTS

CALIBRATION

EXPOSURE — 1month; 3 months

ETCHING — *background*, *calibration,* *measurements* } *detectors*

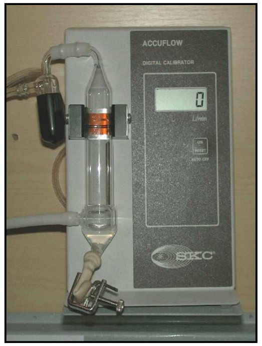
READING

CALIBRATION FACTORS → **CALCULATION**

RESULTS [Bq/m^3]

RADON CALIBRATION CHAMBER

CONTROL BOARD



DIGITAL FLOW METER

MASTERFLEX PUMP

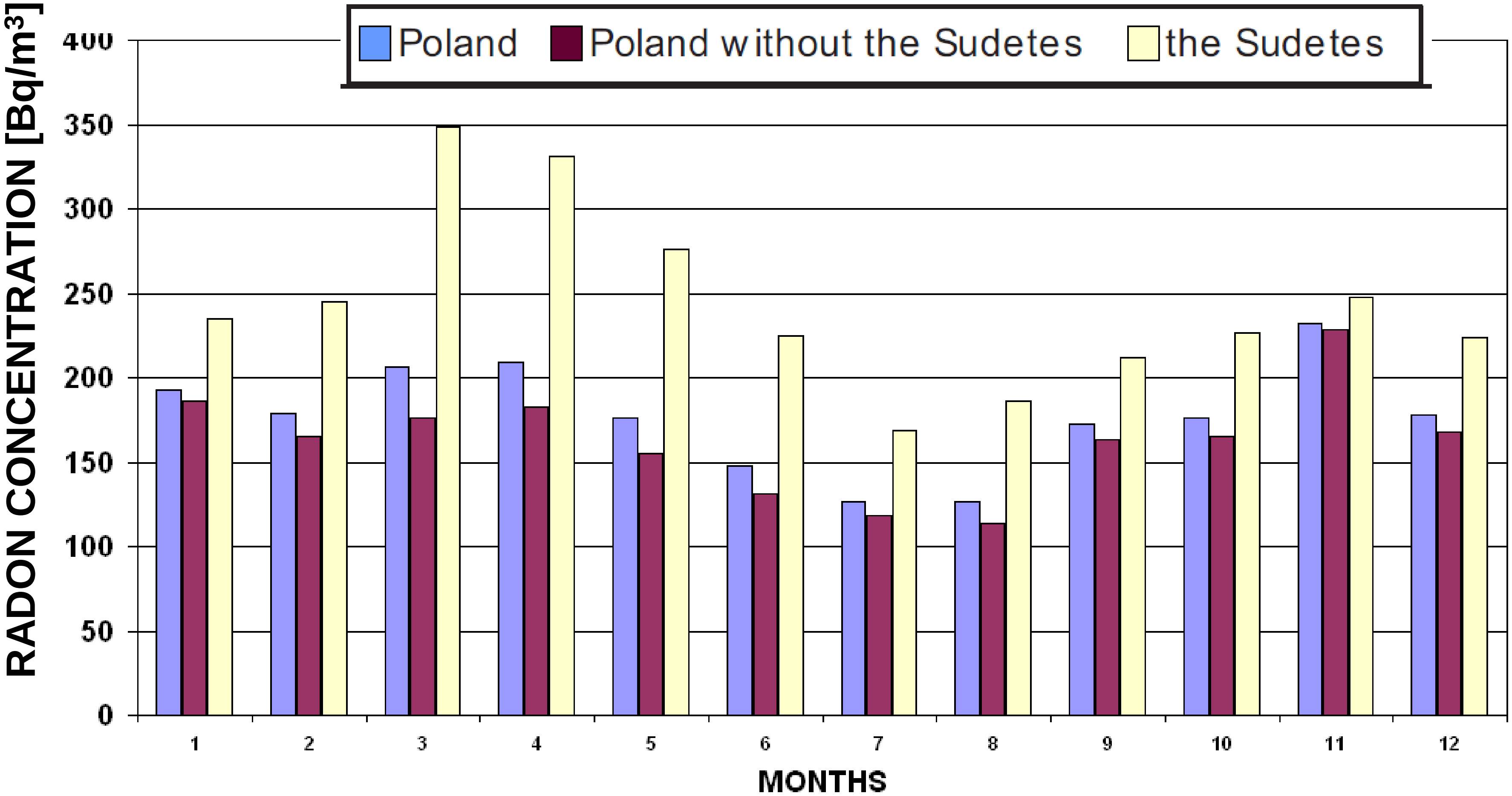
Manually controlled (flow rates: up to 3 dm^3 / min)

TIMER

- control pump
- time on
- time off
- 7 days in week

MEAN MONTHLY Rn

The comparison of mean monthly values of radon concentration in all buildings



Range of results: from 5 Bq/m^3 to 1 770 Bq/m^3.

The lowest mean monthly values in summer, the highest in winter and spring.

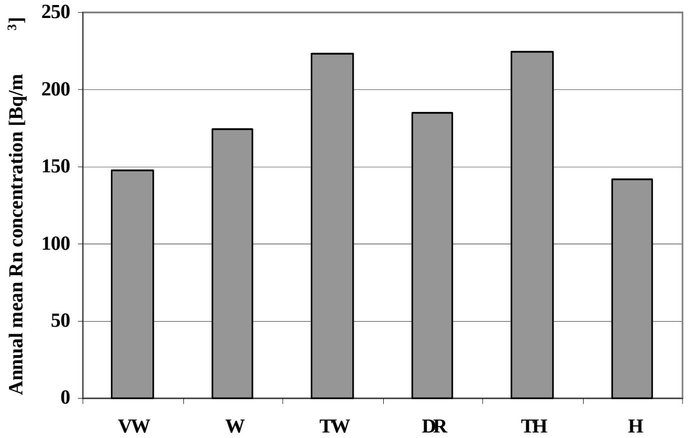
MEAN MONTHLY Rn

The mean monthly radon concentrations (AM) for buildings with basements (full or partly) with analogous values for buildings without a basement were also compared.

- Higher values were understandably observed in buildings without basements.
- Maximal differences reached up to 30% in spring months (March, April).

Radon concentrations in dwellings vary also depending on meteorological conditions.

- **higher mean annual concentrations in buildings situated in <u>temperate warm (TW)</u> <u>and temperate humid (TH)</u> regions**
- **lower values were registered in <u>very warm (VW)</u> <u>and humid (H)</u> areas.**



FURTHER ANALYSIS

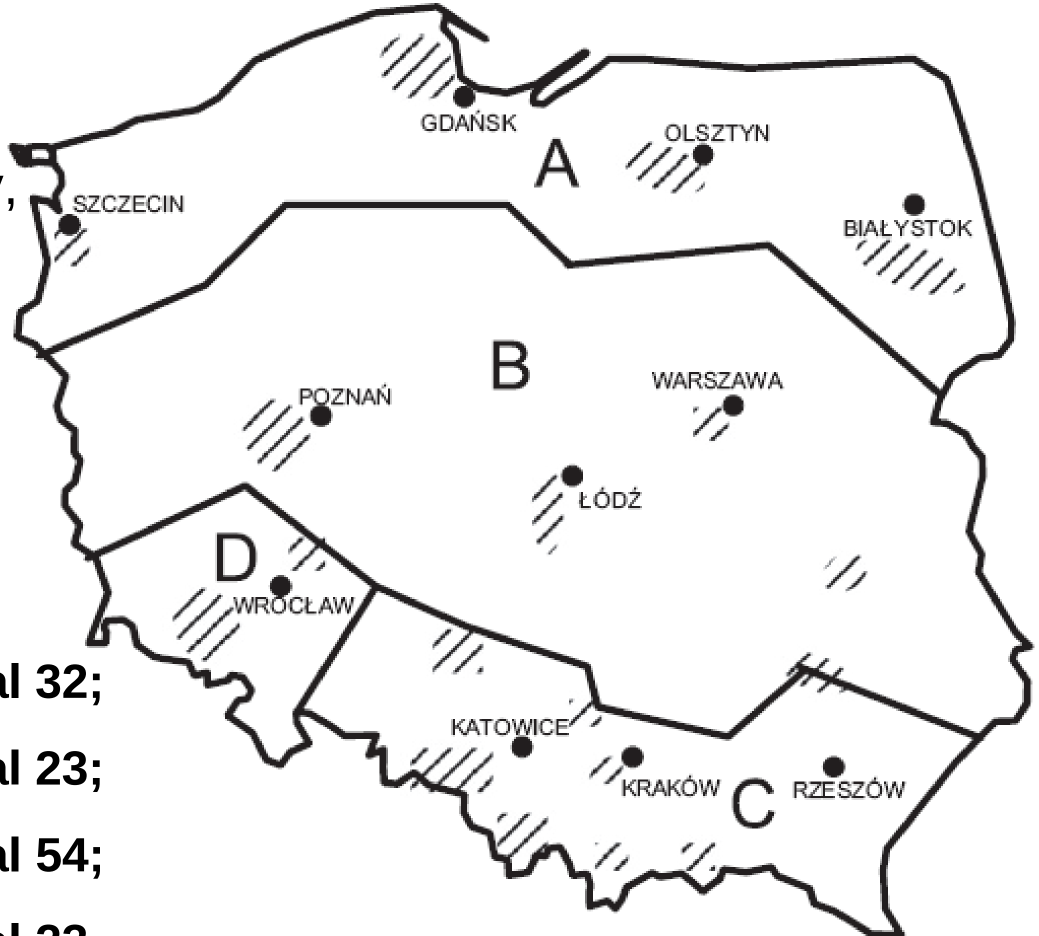
The area of Poland is diverse
as far as thermal–precipitation zones are concerned

A - temperate-warm and dry;

B - warm, temperate-humid and dry;

C - warm and humid;

D - warm, humid
and radon prone Sudety area.



Region A: 28 (bs), 4 (no-bs), in total 32;

Region B: 14 (bs), 9 (no-bs), in total 23;

Region C: 36 (bs), 18 (no-bs), in total 54;

Region D: 15 (bs), 8 (no-bs), in total 23.

SEASONAL CORRECTION FACTORS

The correction factor k_{1m} was calculated on the basis of the geometric mean of monthly values GM_m and the geometric mean GM_Y of annual radon values according to the equation:

$$k_{1m_i} = \frac{GM_Y}{GM_{m_i}}$$

The value GM_Y was evaluated from the results of quarterly exposures of the detectors assuming that the longer exposure time gives more representative values of the mean radon concentrations.

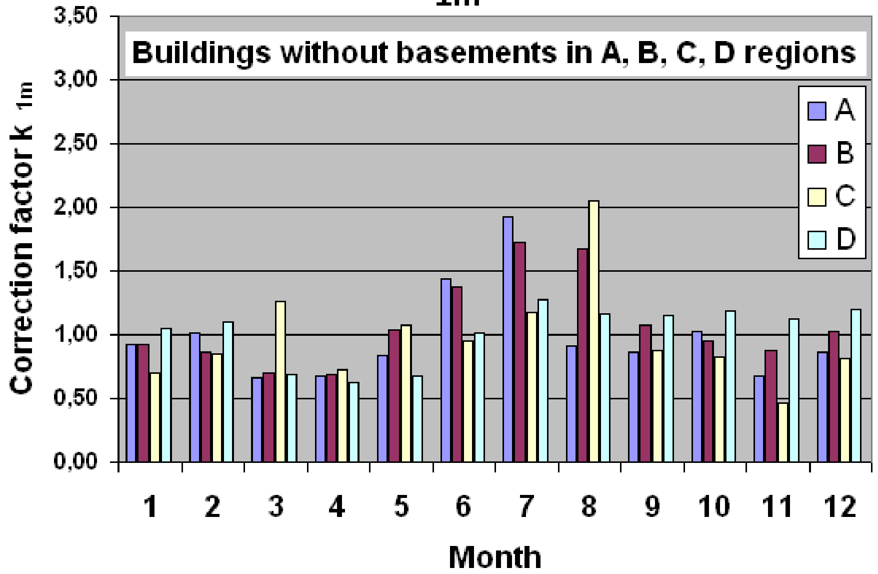
The values of correction factors k_{3m} for the 3-month detectors exposures were calculated as the averages from three consecutive correction factors k_{1m}.

$$k_{3m_i} = \frac{k_{1m_i} + k_{1m_{i+1}} + k_{1m_{i+2}}}{3}$$

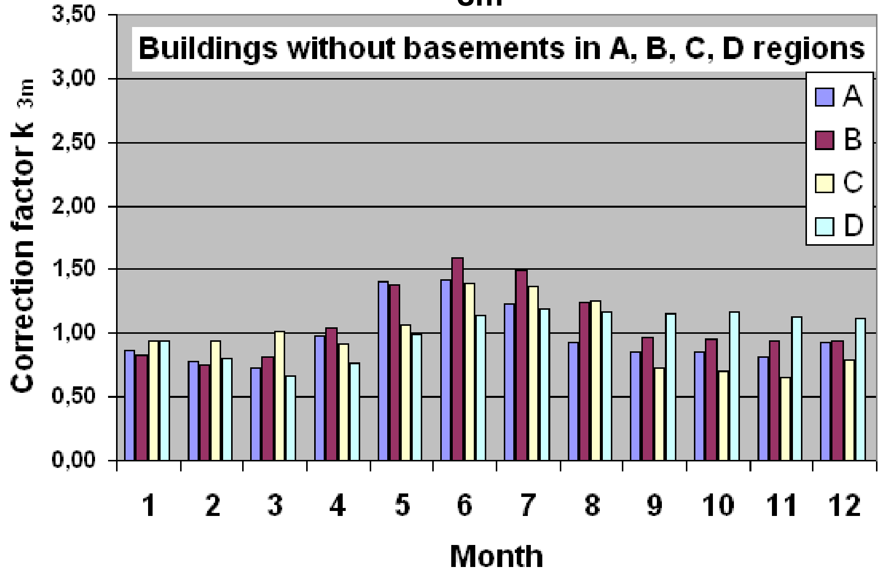
m_i - month of exposure start

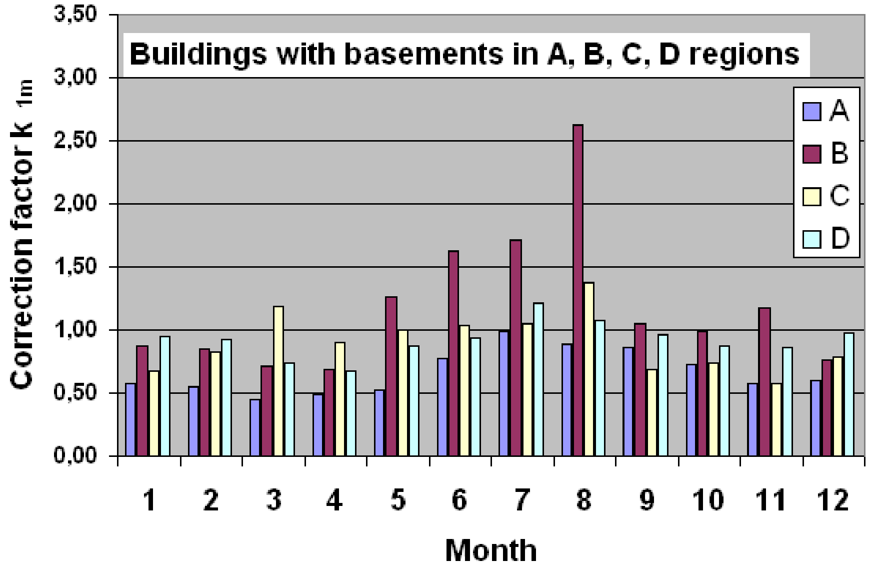
SEASONAL CORRECTION FACTORS

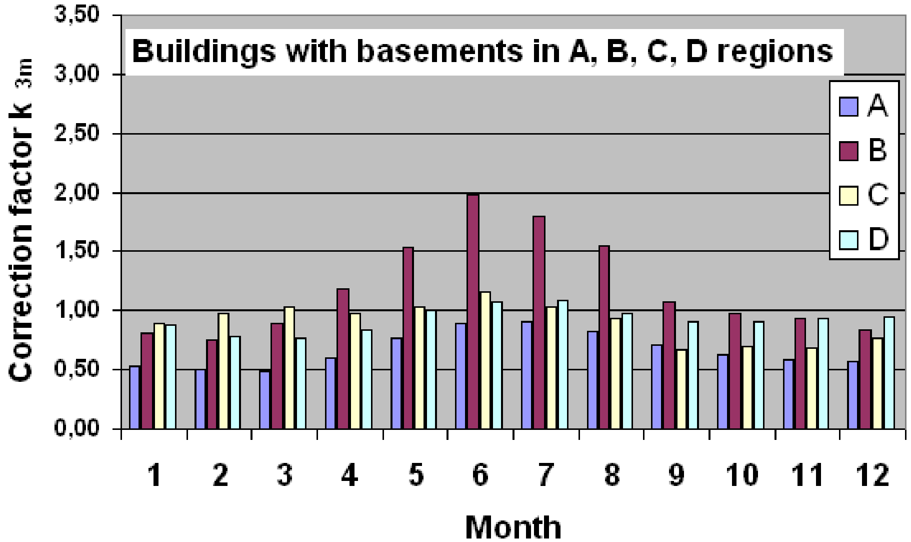
k_{1m}



k_{3m}







ANNUAL RADON CONCENTRATION

Mean annual radon concentration C_{aRn}

on the basis of a measurement conducted:

for one month

$$C_{aRn} = k_{1m} \cdot C_{1mRn}$$

or

for three months

$$C_{aRn} = k_{3m} \cdot C_{3mRn}$$

where:

k_{1m} – the correction factor for a month during which the exposure of the detector is performed,

k_{3m} - the correction factor for the month in which the exposure of the detector commences,

C_{1mRn} – measured radon activity concentration in Bq/m^3, 1-month exposure

C_{3mRn} – measured radon activity concentration in Bq/m^3, 3-month exposure

ANNUAL DOSE CALCULATION

ANNUAL EFFECTIVE DOSES
due to the exposure to radon and progeny in the houses
were calculated by the relation (*UNSCEAR, 2000*):

Annual effective dose:

$$D = C_{Rn} \cdot 0.4 \cdot 7000\ [h] \cdot 9\ [nSv] \cdot [Bq \cdot h \cdot m^{-3}]^{-1}$$

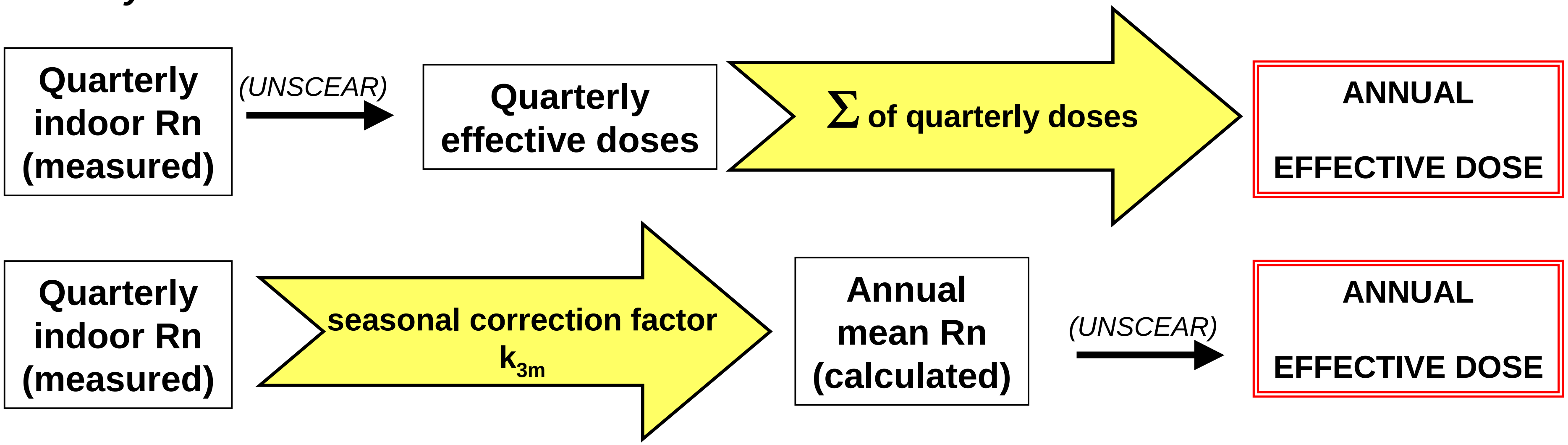
where:

C_{Rn}	- annual average of indoor radon concentration [[Bq/m^3]
0.4	- equilibrium factor for radon and progeny (indoor)
7000 h	- occupancy factor

ANNUAL DOSE CALCULATION

calculated for no-basement buildings in: Sudety region (D) and (B) region

2 ways of calculation:



Point	QUARTERLY INDOOR Rn (measured) [Bq/m³]				QUARTERLY DOSES [mSv]				ANNUAL DOSES [mSv]	
	I quarter	II quarter	III quarter	IV quarter	I	II	III	IV	1st way	2nd way
D-1	309	292	299	280	1,9	1,8	1,9	1,8	**7,4**	**8,7**
D-2	328	224	218	218	2,1	1,4	1,4	1,4	**6,2**	**6,5**
D-3	511	237	283	280	3,2	1,5	1,8	1,8	**8,3**	**8,5**
B-1	92	41	115	115	0,6	0,3	0,7	0,7	**2,3**	**2,8**
B-2	54	31	86	78	0,3	0,2	0,5	0,5	**1,6**	**2,1**
B-3	278	197	132	157	1,8	1,2	0,8	1,0	**4,8**	**7,9**

CONCLUSIONS

The highest values of the correction factors were obtained for detector exposures performed in region B *(warm-W, temperate humid -TH, dry -DR)*, regardless of the type of building. The explanation may be the fact that region B incorporates a big part of Poland in which thermal – precipitation conditions differ from those observed in other regions.

The correction factors are bigger than 1 in the spring – summer season (from May to September) – then the activity of radon concentration is usually much lower than in the other months of the year.

The smallest values of the correction factors were obtained for the autumn – winter season, when the activity of radon in dwellings is higher.

These regularities were found for buildings both with and without basements and were independent of the thermal – precipitation regions.

Significantly higher concentrations of radon were observed in buildings situated in the Sudety Mts. area (Lower Silesia voivodeship)
in all seasons of the year.

CONCLUSIONS

The estimation of the mean annual radon concentration as well as the calculation of the dose due to radon inhalation are more precise if they are based on 3-month exposure of a track-etched detector.

SEASONAL CORRECTION FACTORS CANNOT BE USED FOR:

- ✓ buildings with air conditioning
- ✓ large room with no windows
- ✓ the upper floors with central staircase
- ✓ school

The second problem is the proper determination of equilibrium factor F

For indoor radon F = 0.4

It is dependent on aerosol particle concentration and size distribution

ACKNOWLEDGEMENT

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1.	**IFJ PAN**	**Institute of Nuclear Physics PAN,**	***Kraków,***
2.	**UM**	**Medical University of Bialystok,**	***Białystok*,**
2.	**CLOR**	**Central Laboratory for Radiological Protection,**	***Warszawa*,**
3.	**UŚ**	**University of Silesia,**	***Katowice*,**
5.	**PWr**	**Wrocław University of Technology,**	***Wrocław*,**
6.	**ITB**	**Institute of Building Technology,**	***Warszawa*,**
7.	**GIG**	**Central Mining Institute,**	***Katowice*,**
8.	**IMP**	**Institute of Occupational Medicine,**	***Łódź*.**

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K. Kozak et al. / Applied Radiation and Isotopes 69 (2011) 1459–1465
Correction factors for determination of annual average radon concentration
in dwellings of Poland resulting from seasonal variability of indoor radon

Thank you for your attention

Děkuji vám za pozornost

Jadwiga Mazur

DODATKI

Mean annual 222Rn concentration in homes located in different geological regions of Poland - first approach to whole country area

T.Przylibski et al.. Journal of Environmental Radioactivity 102 (2011) 735-741

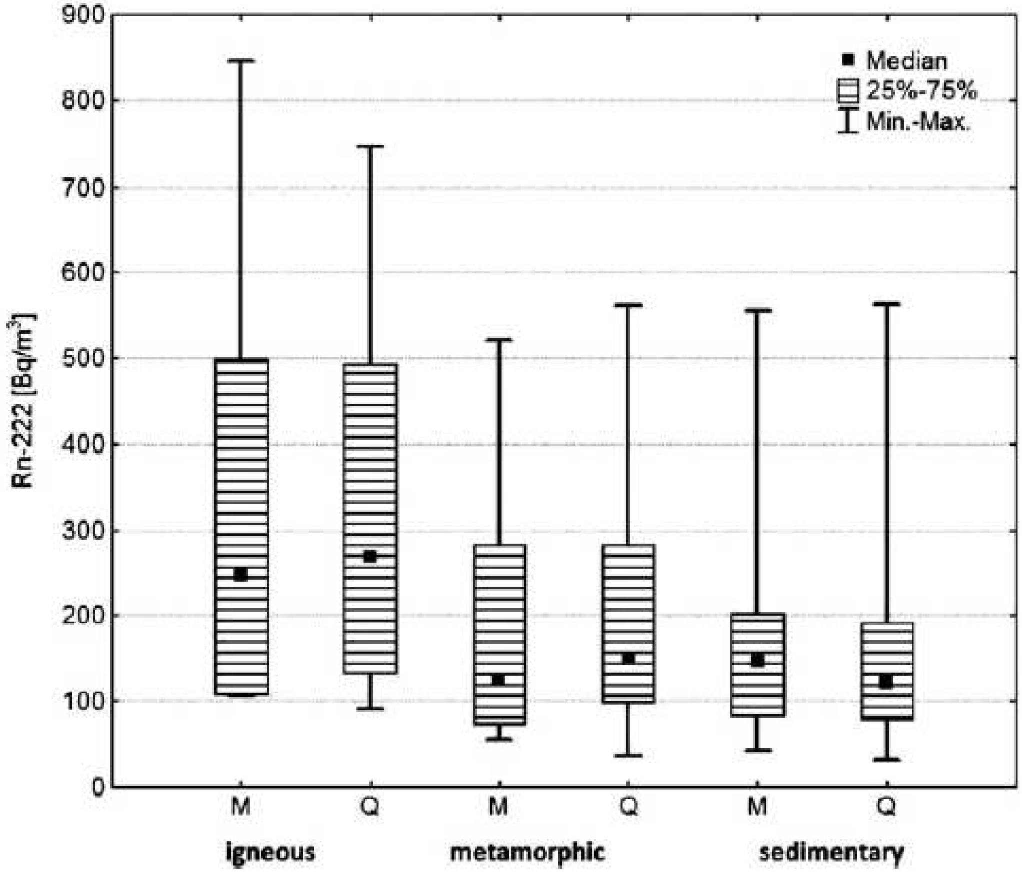

Fig. 3. Distributions of mean annual values of ^{222}Rn activity concentration in buildings founded on sedimentary, metamorphic and igneous rocks in Poland. Mean annual values of ^{222}Rn activity concentration calculated from monthly (*M*) and quarterly (*Q*) measurements.

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STATISTICAL

Month	III 2008	IV 2008	V 2008	VI 2008	VII 2008	VIII 2008	IX 2008	X 2008	XI 2008	XII 2008	I 2009	II 2009
AM	207	209	176	148	127	126	172	176	232	178	193	179
GM	140	163	129	109	94	82	130	136	167	139	152	140
Median	150	152	132	119	101	87	129	128	146	127	156	141
Sd	206	161	149	129	124	141	139	148	195	154	158	154
Min	8	30	26	21	9	5	25	13	26	26	17	17
Max	1769	755	648	712	935	1100	782	945	1253	1339	1200	1359
N	130	129	130	130	130	129	130	130	128	130	128	130
CL (95%)	36	28	26	22	21	25	24	26	34	27	28	27

Season	Spring (III – V.2008)	Summer (VI – VIII.2008)	Autumn (IX – XI.2008)	Winter (XII.2008 – II.2009)
AM	186	151	172	173
GM	137	112	133	130
Median	131	125	123	128
Sd	149	126	145	149
Min	19	23	29	14
Max	723	801	869	1113
N	128	129	129	110
CL (95%)	26	22	25	28

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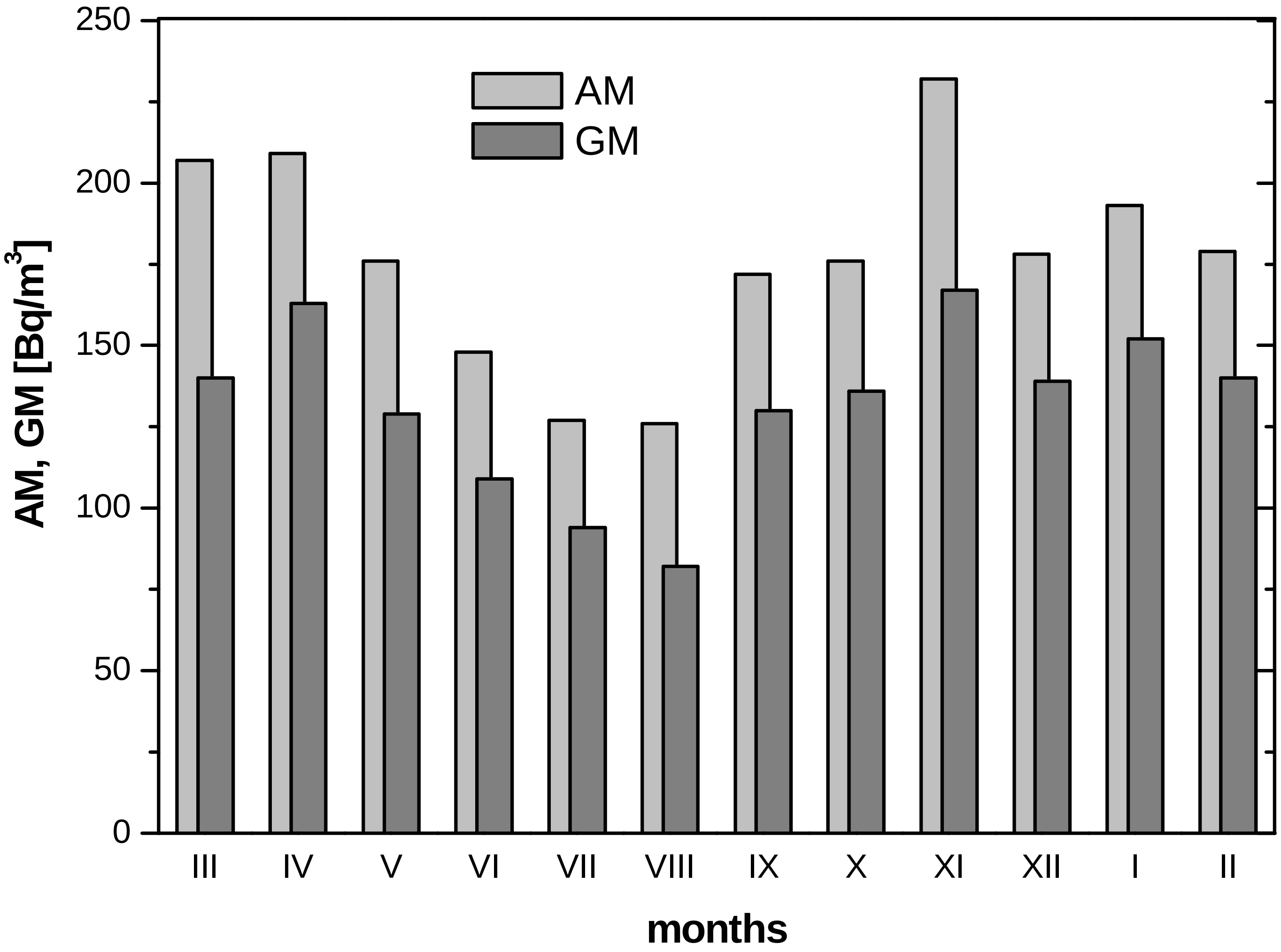
ARITHMETIC & GEOMETRIC AV.



k_{1m}

Month of exposure	k_{1m}							
	A		B		C		D	
	bs	no-bs	bs	no-bs	bs	no-bs	bs	No-bs
I	0.57	0.92	0.88	0.92	0.67	0.70	0.95	1.05
II	0.55	1.01	0.85	0.86	0.83	0.85	0.93	1.10
III	0.45	0.66	0.71	0.70	1.19	1.26	0.74	0.69
IV	0.49	0.67	0.69	0.69	0.90	0.72	0.68	0.62
V	0.53	0.84	1.26	1.04	1.00	1.08	0.88	0.68
VI	0.78	1.44	1.62	1.38	1.04	0.95	0.94	1.01
VII	0.99	1.92	1.71	1.73	1.05	1.17	1.21	1.27
VIII	0.89	0.91	2.62	1.68	1.37	2.05	1.08	1.16
IX	0.86	0.86	1.05	1.08	0.69	0.88	0.96	1.15
X	0.72	1.03	0.99	0.95	0.74	0.83	0.88	1.19
XI	0.57	0.67	1.17	0.88	0.57	0.46	0.86	1.12
XII	0.60	0.86	0.76	1.03	0.79	0.81	0.98	1.20

k_{3m}

Month of exposure start	k_{3m}							
	A		B		C		D	
	bs	no-bs	bs	no-bs	bs	no-bs	bs	No-bs
I	0.52	0.86	0.81	0.83	0.90	0.94	0.87	0.95
II	0.50	0.78	0.75	0.75	0.97	0.94	0.78	0.80
III	0.49	0.72	0.89	0.81	1.03	1.02	0.77	0.66
IV	0.60	0.98	1.19	1.04	0.98	0.92	0.83	0.77
V	0.77	1.40	1.53	1.38	1.03	1.07	1.01	0.99
VI	0.89	1.42	1.98	1.60	1.15	1.39	1.08	1.15
VII	0.91	1.23	1.79	1.50	1.04	1.37	1.08	1.19
VIII	0.82	0.93	1.55	1.24	0.93	1.25	0.97	1.17
IX	0.72	0.85	1.07	0.97	0.67	0.72	0.90	1.15
X	0.63	0.85	0.97	0.95	0.70	0.70	0.91	1.17
XI	0.58	0.82	0.94	0.94	0.68	0.66	0.93	1.12
XII	0.57	0.93	0.83	0.94	0.76	0.79	0.95	1.12

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SEASONAL CORRECTION FACTORS

Taking into account the fact that the distribution of the mean monthly radon concentration values obtained from the track detectors readings were not normal,

the geometric means GM were chosen as the parameters describing the mean radon concentrations within each month.

The values GM_Y were evaluated from the results of quarterly exposures of the detectors assuming that the longer exposure time gives more representative values of the mean radon concentrations.

SEASONAL CORRECTION FACTORS

- The correction factors for exposures lasting 1 month (k_{1m}) or 3 months (k_{3m}) were calculated separately for four chosen thermal – precipitation regions in Poland,
- In each region the correction factors were calculated separately for buildings with and without basements.
- The largest differences in correction factors values were observed in the summer months (June, July, August).
- The differences in the correction factor values calculated for a particular region and for two kinds of buildings (bs and no-bs) reached up to 90%.

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CALIBRATION

CALIBRATION FACTOR is determined taking into account track density of calibration detectors exposed in known radon concentration in radon chamber:

$$k = \frac{\overline{N_k} - \overline{N_t}}{E}$$

Knowing exposure time and track density for measuring detector as well as track density for background detectors, we can calculate average radon concentration during exposure:

$$C = \frac{N_p - \overline{N_t}}{t * k}$$

k – calibration factor [tracks m^3 Bq^{-1} h^{-1} cm^{-2}]

N_k – average track density for calibration detectors [tracks/cm^2]

N_t – average track density for background detectors [tracks/cm^2]

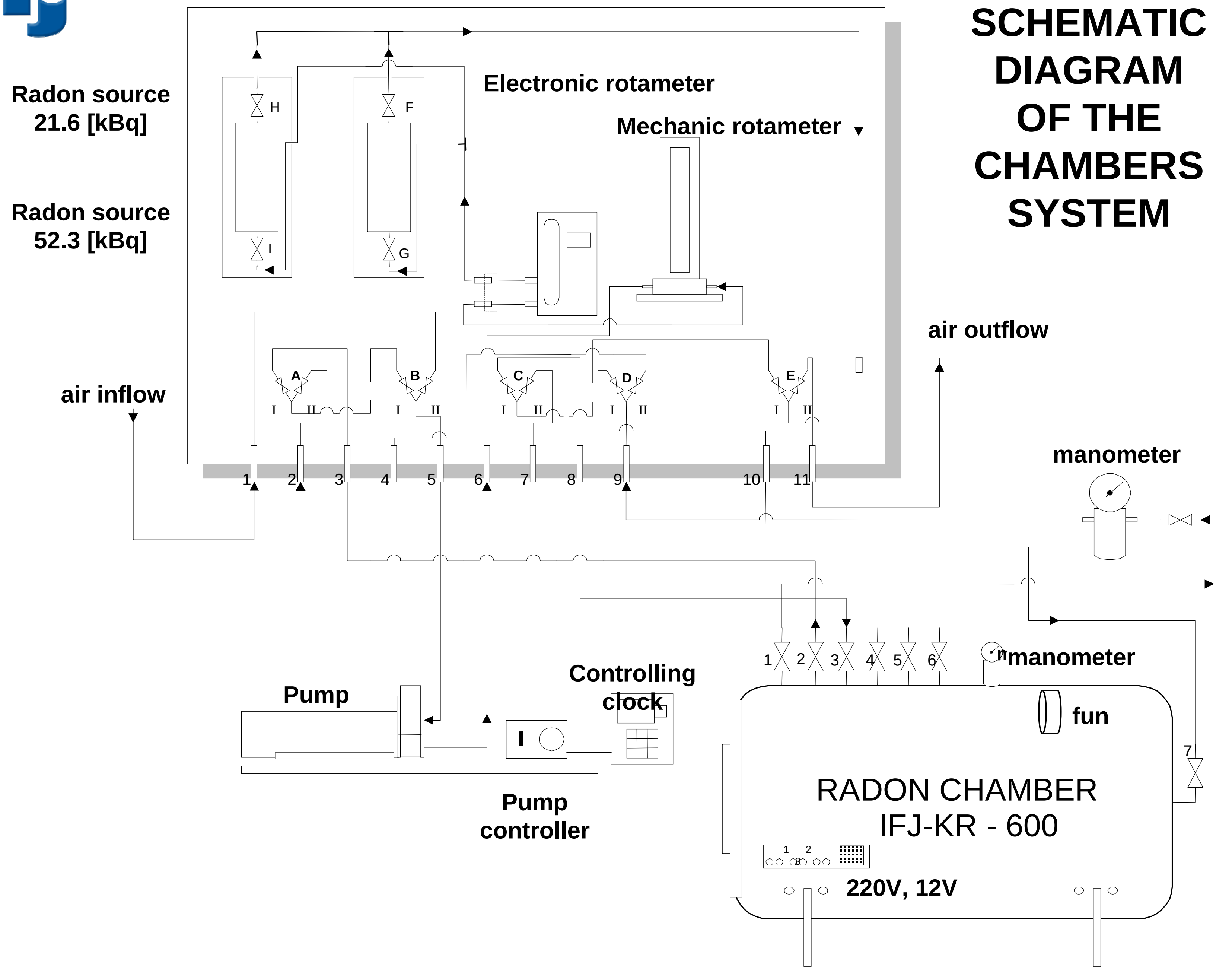
C – radon concentration [Bq/m3]

E – exposure of calibration detectors [Bq h m^{-3}]

t – exposure time [h]

RADON CHAMBER SYSTEM

SCHEMATIC DIAGRAM OF THE CHAMBERS SYSTEM



IDEA OF MEASUREMENTS

ANNUAL RADON CONCENTRATION →
essential value for the determination
of the annual dose due to radon inhalation

The assessment of the mean annual radon concentration on the basis of 1-month or 3-month indoor measurements

How to determine
the annual average radon concentration
on the basis the short-term radon measurements ?