International Intercomparison Exercise on Natural Radiation Measurements under Field Conditions

Saelices el Chico (Spain), May 2011

José Luis Gutiérrez-Villanueva, Carlos Sainz Fernández, Ismael Fuente Merino, Luis Quindós López, Jorge Quindós López, Alicia Fernández Villar, Sara Eva Casal Ordas, David López Abascal, Diego Arteche Laso, Enrique Fernández López, Luis Santiago Quindós Poncela

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Summary

Natural radioactivity is the main component of the annual effective dose received by the general public. Among them, radon gas contributes around 50 % to the total amount of radioactive dose for the general public. The European Directive 96/29/EURATOM mandates the monitoring of occupational radiation exposures which must be done by approved dosimetry services. There is a large number of laboratories in the European Union whose main activities concern the measurement of natural radioactivity. For the particular case of radon gas, legislation in the different countries differs; from obligatory control of radon gas in countries such as the Republic of Ireland, the Nordic countries and the Czech Republic, to recommended monitoring in countries such as Spain or Italy as an example. Moreover, there are two recommendations on radon gas in the European legislation suggesting levels of radon gas indoors for new and existing houses as well as radon reference level for drinking water.

Another important part of the effective due to natural sources for the general public is composed of external gamma radiation. There is no reference value in European legislation which applies to external gamma radiation. However the measurement of this parameter is quite important in order to assure a precise and accurate result for the total effective dose.

Thus we can observe that two elements, radon and external gamma dose, are of high importance and it is necessary to ensure that the values provided by the different laboratories are accurate. One of the most common ways to assure the quality of the results of laboratories is by means of intercomparisons carried out by approved services most of the time belonging to reference laboratories. Here we can cite those intercomparison exercises done annually by Bundesamt für Strahlenschutz (BfS) in Germany and Health Protection Agency (HPA) in United Kingdom both on the measurement of radon gas. Frequently, the International Atomic Energy Agency (IAEA) invites laboratories to carry out intercomparisons to test different parameters such as the detection of radionuclides through gamma spectrometry.

Intercomparisons are a very important tool for measurement services and laboratories in order to detect potential problems and perform rectifications as well as to provide calibrations for instruments using international standards. The common scenario for the typical intercomparison exercise is the exposure of the instrument to a reference atmosphere of the parameter to control (i.e. radon gas) under temperature, humidity and atmospheric pressure stable conditions. However as we know these are not the common situations we can find in a normal dwelling when measuring radon gas. So the existence of facilities where it could be possible to test instruments for the measurement of radon gas and external gamma radiation under changing conditions of meteorological parameters becomes necessary

The Radon group from University of Cantabria in Spain has established a site where the values of natural radioactivity are high enough to test instruments and detectors under typically variations of temperature, humidity and atmospheric pressure which we can find in occupancy places (dwellings and working places). Such a place is located in an old uranium mine site in which was held the first intercomparison exercise under field conditions in May 2011 (IFC11). A total number of 41 laboratories from different European countries took part in the activities involving the measurement of radon gas and external gamma radiation. This report shows the results of the intercomparison as well as discussions of the achieved results. The appendix contains the list of participants as well as a list of participants' comments in order to improve this intercomparison in future years.

Acknowledgements

First of all, the Radon group (University of Cantabria, Spain) wishes to express its more sincere gratitude to the national uranium company of Spain (ENUSA) for the interest it has shown over a long period of time in the subject of natural radioactivity and the activities carried out by the Radon group. Special thanks also to the local staff of the facilities situated in Ciudad Rodrigo (Saelices el Chico, Salamanca) and the general manager of this branch of ENUSA.

We would also like to say thank you to the Spanish Nuclear Safety Council (CSN) whose funding for this intercomparison was very useful for the correct development of all the activities.

However, this exercise could not have been possible without the collaboration of all the participants who took part in it (see Figure 1). Their interest and comments contributed to a fruitful success and reflected their interest in such kinds of exercises.

The participation of some reference laboratories from Germany (BfS) and United Kingdom (HPA) gave a special value to this intercomparison as well as some producers of radon detectors and measurement instruments such as SARAD, RADOSYS, GAMMADATA and MIAM which carried out and tested their instruments and detectors.

We also would like to mention the contribution to this report of CIEMAT which improve the sections on external gamma radiation. We are deeply indebted to Martin Neznal and Matéj Neznal (Radon vos) for their help with the analysis of the exercise of radon in soil. A detailed analysis on this exercise is included in the Appendix II of this report.

Finally we would like to make a special acknowledgement to Jon Miles (HPA, UK) who participated as external advisor and shared his long experience on radon detection with all the participants contributing to improve the quality of this intercomparison exercise.

Figure 1: Participants in the Ist International Intercomparison of natural radiation under field conditions, May 2011

1 Introduction

The first intercomparison on natural radioactivity under field conditions was held in the old uranium mine of ENUSA in the municipality of Saelices el Chico (Salamanca, Spain) from 23rd to 27th of May 2011. The meeting was organized by the Radon group of University of Cantabria (Spain) headed by Prof. Luis S. Quindos Poncela. The main objective of this event was to test different instruments and detectors for the measurement of radon gas and external gamma radiation (dose rate) in real conditions in a place where the levels of natural radiation are quite high.

The old uranium mine site was shut down in 2004. Since then, the restoration process has been taking place. During these activities, one of the buildings used for the treatment of uranium mineral was chosen to become a laboratory of natural radiation (LNR) in order to be used for the calibration and testing of instruments and detectors for the measurement of natural radiation. Modifications in the primitive building were done and two new rooms were constructed using new materials. Thus we can assure that there is no contamination remained in the rooms used for the radon indoors exposures. The Radon Group in collaboration with ENUSA was in charge of the activities of adaptation of this building to the new situation.

The first circular of the intercomparison exercise was distributed during the fall of 2010. Soon the response of the laboratories and research groups involved in natural radiation was received and they showed an interest to take part in this particular event. At the beginning of 2011 a preliminary list of participants was available and the Radon Group decided the activities of the exercise. The main goal was the measurement of radon gas in different scenarios such as water, soil gas, indoors, outdoors and exhalation rate. The existence in the surroundings of the LNR of tailings from the mining process suggested the performance of an extra exercise devoted to the measurement of the external dose rate would be useful. Thus the activities planned to be held are summarized in the next list:

- External gamma dose rate
- Radon indoors with active and passive detectors
- Radon outdoors
- Radon in water
- Radon exhalation rate from building materials
- Radon exhalation rate from soil
- Radon in soil gas

A total number of 45 participant institutions (approximately 100 persons) decided to take part in the exercise coming from the following countries: Austria, Belarus, Belgium, Czech Republic, France, Germany, Hungary, Italy, Norway, Poland, Portugal, Romania, Slovenia, Spain, Sweden and United Kingdom. The institutions involved were universities, reference laboratories and commercial companies whose main activities are related to the measurement of natural radiation and radon gas and external gamma radiation in particular. Figure 2 shows a map of Europe with the location of the participant institutions.

Figure 2: Participant institutions in the IFC11

The number of participants in each activity can be seen in Table 1. However some activities did not have enough number of participants in order to get representative results and they are not included in this report (radon outdoors and radon exhalation rate from soil and building materials).

Table 1: Exercises and number of participants

Activity	Number of participants
Radon indoors (passive detectors)	25
Radon in soil gas	18
Radon indoors (active detectors)	17
Radon in water	13
External gamma dose rate	13

The activities carried out at IFC11 consisted not only in the practical exercises of measuring natural radiation summarized in Table 1 but also in different lectures given by international experts from different fields of natural radioactivity who are recognized worldwide. Table 2 shows a list of all the lectures presented at the IFC11 and extra lectures not directly related with the topic of the meeting.

Table 2: Presentations given at IFC11

Title	Speaker	Institution
Chernobyl Accident: 25 years later	Leonid Chunikhin	RC Radiation Medicine, Gomel, Belarus
The Radon Calibration Laboratory at the Federal Office for Radiation Protection (BfS)	E. Foerster	BfS (Federal Office for Radiation Protection), Germany
Measurement of External Environmental Gamma Radiation	J.C. Sáez Vergara	CIEMAT, Spain
Radon gas intercomparisons	Jon Miles	HPA, UK
Mi.am srl	Antonio Parravicini	Mi.am, Italy
Soil gas radon intercomparisons	Martin Neznal	RADON v.o.s., Czech Republic
Ecological problems of territories suffering from negative impact of metal mining industry	Valentina I. Safarova	Bashkortostan Nature Management and Ecology Ministry
RTM 2200 Radon/Thoron monitor –" System in a box" for complex sampling procedures and multi parameter analysis	Streil, T	SARAD, Germany
Radionuclides in the service of love	Tibor Kovács	University of Pannonia, Veszprem, Hungary
The European Geogenic Radon Map	Peter Bosew	BfS (Federal Office for Radiation Protection), Germany

All participants were invited to take part in the different exercises using the instruments and radon detectors they normally use in their routine work. Hence, a wide range of equipment was tested as well as radon passive detectors exposed during the exercise. The origin of the participants was also quite different covering most of the actors involved in the measuring of natural radioactivity. There were members of universities and research centres, official institutions such as BfS, HPA, CIEMAT, and also private companies. The sponsors of IFC11, ENUSA and CSN, also attended the meeting as observers.

This report presents the main results obtained in all the exercises. Each section starts with the keynote lecture given at the intercomparison related to the exercise summarized in the section. The participants are identified by a unique alphanumeric code in order to preserve the confidentiality of the laboratory. The exercise corresponding to radon exhalation rate from building materials is not included in the report due to low number of participants.

2 Measurement facilities

2.1 Introductory keynote by ENUSA

www.enusa.es

ENUSA
INDUSTRIAS AVANZADAS, S.A.

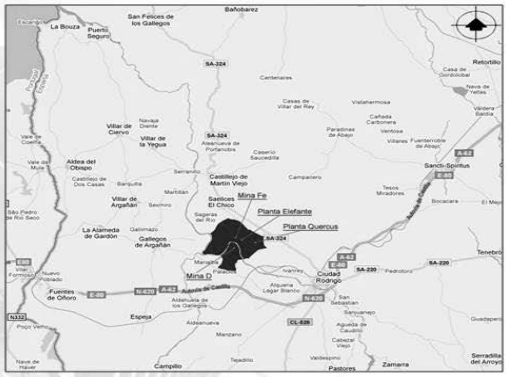
URANIUM MINING AND RESTORATION ACTIVITIES

CENTRO MEDIOAMBIENTAL DE CIUDAD RODRIGO

www.enusa.es

ENUSA INDUSTRIAS AVANZADAS, S.A.

GENERAL LOCATION

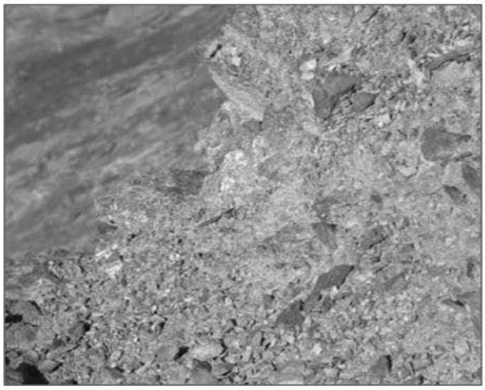


www.enusa.es

ENUSA INDUSTRIAS AVANZADAS, S.A.

URANIUM MINERALIZATIONS

Primary: pitchblende and black oxides (pyrite and carbonates)



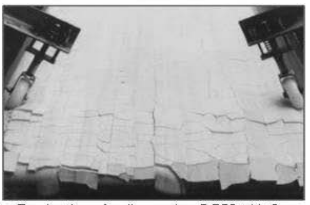
Secondary: sulphates and others

ENUSA INDUSTRIAS AVANZADAS, S.A.

SUMMARY OF MINING ACTIVITIES (1974 – 2000)

Rock: 81 Mt (strip. ratio: 5.7)

Mineral: 12 Mt (medium grade U_3O_8= 650 ppm)



Production of yellow cake: 5 750 t U_3O_8 (maximum 300 t U_3O_8/year)

ENUSA INDUSTRIAS AVANZADAS, S.A.

SUMMARY OF RESTORATION AND DECOMISSIONING ACTIVITIES (2001 - ?) 1/2

- **One of the most important projects in Europe for its development and budget**

Open pits: 15 Mm³

Wastedumps: 35 Mm³

Old mineral stockpiles: 4 Mm³

Tailings dumps: 1 Mm³

Metallurgical facilities: Elefante and Quercus plants

Total surface affected by activities: 300 ha

www.enusa.es

ENUSA INDUSTRIAS AVANZADAS, S.A.

SUMMARY OF RESTORATION AND DECOMISSIONING ACTIVITIES (2001 - ?) 2/2

Rock volume (with covering materials): 22 M m³

Water dumps and ponds: 1M m³

New drainages and channeling: 10 km

Surface revegetated: 250 ha (380 kg/ha)

www.enusa.es

ENUSA INDUSTRIAS AVANZADAS, S.A.

ADVANCE IN RESTORATION ACTIVITIES 1/3

December 2000

March 2005

ENUSA INDUSTRIAS AVANZADAS, S.A.

ADVANCE IN RESTORATION ACTIVITIES 2/3

May 2004

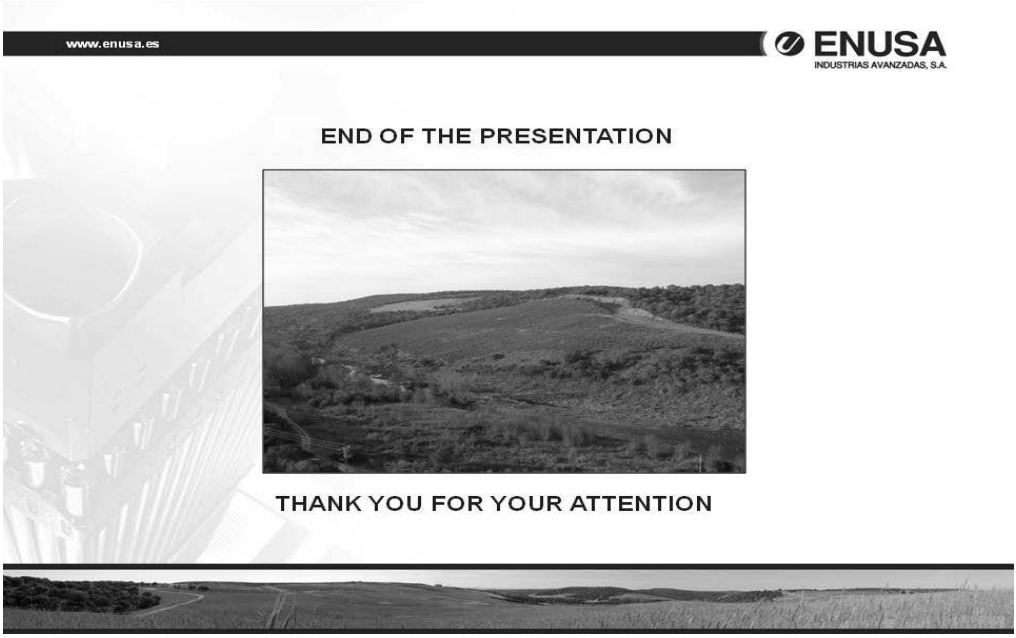
March 2009

ENUSA INDUSTRIAS AVANZADAS, S.A.

ADVANCE IN RESTORATION ACTIVITIES 3/3

June 2006

February 2010



2.2 Logistical arrangements

The exercises were carried out in one of the buildings of ENUSA used in the past for uranium mineral treatment. LaRUC in collaboration with ENUSA was in charge of arranging the building in order to convert it to a laboratory of natural radioactivity but with natural levels of radon gas indoors. These levels are also affected by daily changes of weather conditions which make the place suitable for studying radon variations indoors.

The place is a two-storey building. In the ground level, 2 radon chambers were built with high radon levels in each. The possibility of using artificial ventilation systems allows controlling the natural radon concentrations. Each of these rooms are equipped with electrical plugs for connecting radon active monitors as well as shelves for the installation of passive radon detectors. There is a big room with approximately 25 working places all of them with electrical plugs to connect laptops or measurement instruments. All the participants attending the intercomparison were allocated with a working space identified by the institutions' name. Another room was used for the exercise of radon in water and working space for the organizers of the meeting. The second floor is composed by a big room with radon concentrations typically between 200 – 100 Bq m^{-3}. There is also a conference room which was used for the meetings before each exercise and also presentations and keynote lectures. A 9x9 m square was prepared in the surroundings of the building to be used as experimental field for external gamma dose rate.

Concerning the identification of the participants, all of them have been provided with a unique alphanumeric code (IFC11_XX). The code guarantees the confidentiality of the results and also permits to compare the data obtained in the activities. In those cases when the laboratory submitted 2 or more sets of detectors or instrument for an exercise, the coding system is modified to allow

distinguishing of different sets (IFC11_XX_i where i=a,b,c, etc.). The activities and other events during the intercomparison are summarized in Table 3.

Table 3: Schedule of the IFC11

DAY	9h	10h	12h	13h	14h	18h	19h
Monday, 23	**RECEPTION**			**OFFICIAL WELCOME**	INFORMAL LUNCH	RADON IN WATER & RADON EXHALATION RATE FROM BUILDING MATERIALS	TALKS: The European Geogenic Radon Map by Peter Bosew 25 years after Chernobyl accident By Dr. Chunikhin Leanid Alexandrovich
Tuesday, 24	TALK: Radon gas Intercomparisons by Jon Miles	REMARKS FOR MEASUREMENTS		RADON EXPOSURE A	**OFFICIAL RECEPTION AT CITY HALL**	**LUNCH**	**GUIDED VISIT TO CIUDAD RODRIGO**
Wednesday, 25	TALK: Soil Radon Gas Intercomparisons by M. Neznal	REMARKS FOR MEASUREMENTS		RADON EXPOSURE B & RADON EXPOSURE C	INFORMAL LUNCH	RADON IN SOIL & RADON EXHALATION RATE FROM SOIL	
Thursday, 26	TALK: External Gamma Radiation Measurement by J.C.Saez & E. Correa	REMARKS FOR MEASUREMENTS		EXTERNAL GAMMA RADIATION & RADON OUTDOOR	INFORMAL LUNCH	EXTERNAL GAMMA RADIATION	
Friday, 27		PROVISIONAL CONCLUSIONS		CLOSING EXERCISE			

3 Radon in water

3.1 Organization of the exercise

The objective of the exercise was to test different measuring systems of radon in water using a sample with a fix radon concentration. To do this, a barrel containing 100 l of water was connected to a small box containing a soil with high uranium concentration. Thus radon generated by radioactive decay from uranium is pumped into the barrel and can dissolve in the water. The barrel was closed in order to prevent radon leakages. Every participant could take as many water samples as necessary for using its measurement protocol. The sampling was done using a tap installed in the wall of the barrel as we can see in Figure 3.

Figure 3: Detail of sampling for radon in water exercise

The types of instruments or technique used are very different and we can summarize them as: Liquid Scintillation Counting (LSC), Lucas cells, gamma spectrometry, and active devices (RTM from SARAD, Alphaguard, RAD7 and Pylon instruments). A total number of 13 participants decided to participate in this exercise and the list of them appears in Table 4.

Table 4: List of participants in the exercise Radon in water

Country	Institution
Belgium	Federal Agency for Nuclear Control
Czech Republic	RADON v.o.s.
Germany	SARAD
Hungary	University of Pannonia
Italy	ARPAcal
Norway	NRPA (Norwegian Radiation Protection Authority)
Poland	Institute of Nuclear Physics PAN
Portugal	Laboratory of Natural Radioactivity, University of Coimbra
Romania	University Babes-Bolyai/Environmental Radioactivity and Nuclear Dating
Spain	Grupo de Física de las Radiaciones. Departamento de Física. Universidad Autónoma de Barcelona
Spain	Universidad de Extremadura. Badajoz
Spain	University of Extremadura. Caceres
Spain	CIEMAT

3.2 Results and discussion

Each participant was asked to return results in terms of Bq l^{-1} concentration of radon in water. No reference value was set and in addition to concentration values of radon in water, other information was requested such as number of measurements, uncertainty, type of uncertainty and type of instrument used. Among extra requested data, the type of uncertainty was not reported by any participant. Thus the error bars in the Graphs correspond to the uncertainty values given by the participant but there is no information about the type of uncertainty used. A graph containing the results of this exercise is represented in Figure 4.

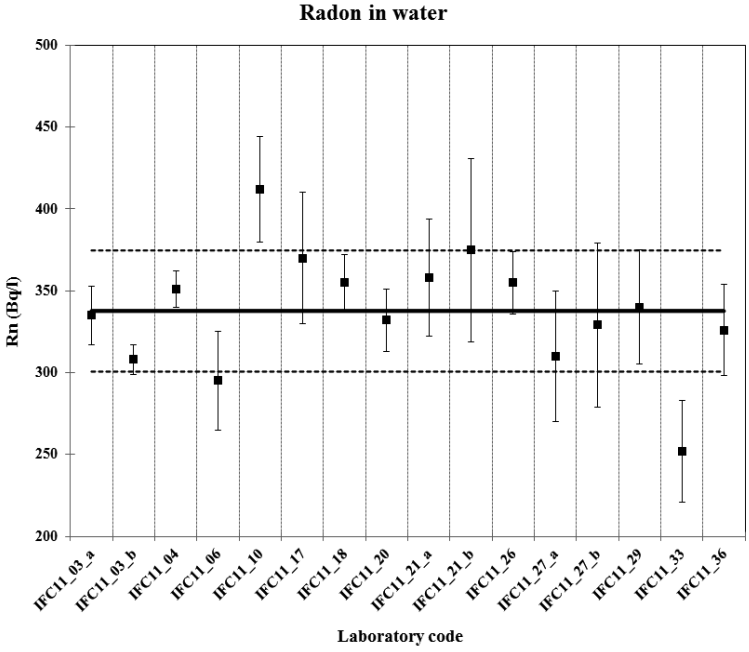


Figure 4: Results of radon in water. Solid line represents the mean value. Dashed lines correspond with one standard deviation

In order to perform a preliminary analysis of the data we have summarized the most important information in Table 5:

Table 5: Results of the exercise "radon in water" and statistical parameters

Mean (Bq l^{-1})	**338**
Maximum (Bq l^{-1})	412
Minimum (Bq l^{-1})	252
Standard deviation (Bq l^{-1})	37
Standard deviation (%)	11

P-value (test test Shapiro-Wilk)	0.87
P-value (test ANOVA)	0.07

The results represented in Figure 4 and Table 5 conclude that all the participants have obtained similar results from statistical point of view. The laboratories with codes IFC11_06, IFC11_10 and IFC11_33 are outside the limits indicated by 1 standard deviation respected mean value. It is also interesting to note that some participants have reported quite large uncertainties. Two of these laboratories were using active devices for measuring radon in water while one gave the result by means of liquid scintillation counting (LSC). Other laboratories are quite close to the border of ±1 standard deviation (IFC11_03, IFC11_17, IFC11_21 and IFC11_27). All of them collected a water sample and later measurement by means of LSC except one which used gamma spectrometry. However, the laboratories IFC11_03, IFC11_21 and IFC11_27 obtained another results which are closer to the mean value of all the participants. It is important to notice that the participant IFC11_03 has used the same technique (LSC) but it got one value very similar to the mean of the rest of the participants. The same applies to IFC11_21 and IFC11_27 but in this case the techniques were different for the different results. A possible explanation for the difference in the results could be attributed to the sampling technique. All the samples were taken in a short interval (2-3 hours). Therefore the participants were opening and closing the tap for the acquisition of the water sample. This situation possibly created disequilibrium in the radon concentration inside the barrel so the radon concentration in the water samples was not exactly the same. Nevertheless the difference should not have been quite important due to the fact that the tap was open some seconds in order to take the water sample. Hence the distribution of the results is quite similar from a statistical point of view as it is shown in the ANOVA test.

4 External gamma dose rate

4.1 Introductory keynote given by Jose Carlos Sáez Vergara

International Intercomparison Exercise on Natural Radiation Measurements

under Field Conditions

Saelices el Chico (Salamanca, Spain), May 23-27, 2011

Measurement of External Environmental Gamma Radiation

J.C. Sáez Vergara, E. Correa Garcés
CIEMAT, Madrid (Spain)

INTRODUCTION

- External environmental dose rate is probably the most used radiological parameter in radiation protection.

- It describes the exposure to external radiation sources, which dominates most of the human practices and is the second in natural sources after radon inhalation.

- In principle, it is easy to measure , standards and calibration preocedures are well established, many instruments are available at reasonable costs, large experience since radioactivity discovery...

BUT ...

EURADOS: Comparison of early warning instruments since 1999

Country	Responsible for national network (Intercomparison)	Other participants (Intercomparison)
AUSTRIA	Federal Chancellery, Vienna (1999)	Bitt Technology (1999)
CZECH REPUBLIC	National Radiation Protection Institute, NRPI (1999)	
DENMARK	Risø National Laboratory, RNL (1999)	
FRANCE	Institute de Radioprotection et Sureté Nucleaire, IRSN (2002)	
GERMANY	Bundesamt für Strahlenschultz, BfS (1999)	Physikalisch-Technische Bundesanstalt, PTB (1999 & 2002)
GREECE	Greek Atomic Energy Commision, GAEC (2002)	Aristotle University of Thessaloniki (2002)
HUNGARY	Paks Nuclear Power Plant (2002)	Atomic Energy Research Institute (2002)
THE NETHERLANDS	National Institute of Public Health and the Environment, RIVM (1999)	
PORTUGAL	Direcçao Geral Ambiente, DGA (1999)	
SPAIN	Consejo de Seguridad Nuclear, CSN (1999)	CIEMAT (1999 & 2002)
SWEDEN	Swedish Radiation Protection Authority, SSI (2002)	
SWITZERLAND	Swiss Nuclear Safety Inspectorate, HSK (2002)	
	Institut de Radiophysique Apliquée, IRA (2002)	
UNITED KINGDOM	No participant	Stirling University (2002)
		Consultant (1999 & 2002)

INSTRUMENTS PARTICIPATING IN EURADOS 1999

ID	Type	Application	Manufacturer	Quantity	Units	Home Source
11	PC	Network	Bitt	H*(10)	nSv/h	Cs137
12	PC	Other	Bitt	H*(10)	nSv/h	Cs137
21	PC	Other	FAG	H*(10)	nSv/h	Cs137
22	PC	Other	Bitt	H*(10)	nSv/h	Cs137
23	PC	Network	Berthold	H*(10)	nSv/h	Cs137
24	GM	Other	Berthold	H*(10)	nSv/h	Cs137
25	IC	Other	Reuter Stokes	X	µR/h	Cs137
26	NaISc	Other	Tesla	Kair	nGy/h	Cs137
31	IC	Other	Reuter Stokes	X	µR/h	Information not supplied
32	IC	Network	Reuter Stokes	X	µR/h	Information not supplied
33	NaISc	Network	Bicron	counting	cps	Cs137
41	GM	Other	Hormann	Hx(10)	nSv/h	Information not supplied
42	GM	Network	Hormann	Kair	nGy/h	Information not supplied
43	GM	Other	Hormann	Kair	nGy/h	Information not supplied
51	PC	Network	Bitt	H*(10)	nSv/h	Co60
52	PC	Other	Bitt	H*(10)	nSv/h	Cs137
53	GM	Other	Genitron	H*(10)	nSv/h	Cs137
61	GM	Network	Hormann	Kair	nGy/h	Cs137
71	PSc	Other	MAB	H*(10)	nSv/h	Cs137
72	GM	Network	Berthold	H*(10)	nSv/h	Cs137
73	GM	Other	Genitron	Kair	nGy/h	Cs137
74	IC	Other	Reuter Stokes	X	µR/h	Cs137

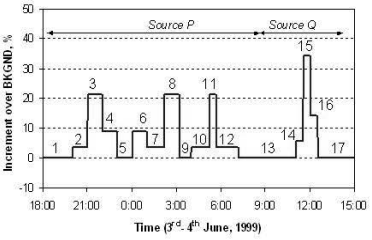
INSTRUMENTS PARTICIPATING IN EURADOS 2002

ID	Type	Application	Manufacturer	Quantity	Units	Home Source
081	GM	Network	Rados	H*(10)	nSv/h	Cs137 and Co60
082	IC	Other	Reuter Stokes	H*(10)	nSv/h	Cs137 and Co60
083	PSc	Other	APVL	H*(10)	nSv/h	Cs137
091	IC	Network	Reuter Stokes	Dair	nGy/h	Cs137
101	PC	Network	Bitt	H*(10)	nSv/h	Cs137
102	PC	Other	Bitt	H*(10)	nSv/h	Cs137
111	PC	Other	Eberline	H*(10)	nSv/h	Cs137
112	GM	Other	Rados	H*(10)	nSv/h	Cs137
113	IC	Network	SSI	H*(10)	nSv/h	Cs137
121	GM	Network	Horman	H*(10)	nSv/h	Cs137
122	IC	Other	Reuter Stokes	H*(10)	nSv/h	Cs137
123	GM	Network	Technidata	H*(10)	nSv/h	Cs137
131	IC	Other	Reuter Stokes	X	µR/h	Co60
132	IC	Other	Reuter Stokes	X	µR/h	Co60

- Most of the instruments measures H*(10)
- Instruments are mostly calibrated using Cs137 sources
- Two instruments use some background value which are automatically substracted from the current measurement

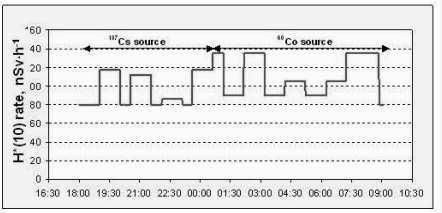
EURADOS: Comparison of early warning instruments since 1999: Risoe 1999

- Automatic device to program controlled gamma plume profiles
- Two ^{137}Cs encapsulated sources whish yield dose increments from 3% to 35%.
- Step time length: 10 minutes
- Plume simulation was produced continuosuly for 20 hours



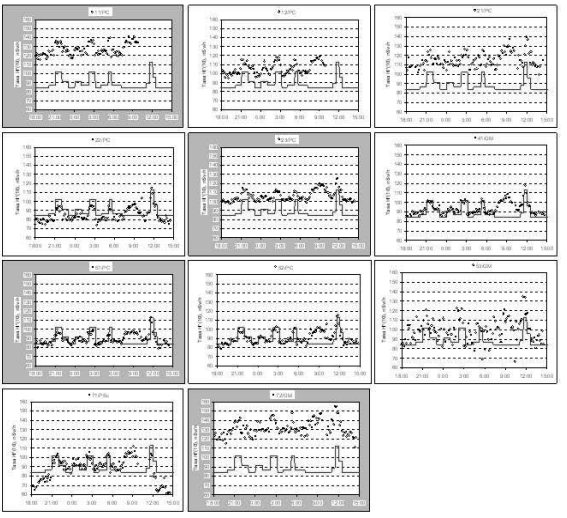
EURADOS: Comparison of early warning instruments since 1999: PTB 2002

- Automatic device to program controlled gamma plume profiles kindly provided by Riso National Laboratory
- ^{137}Cs and ^{60}Co encapsulated sources yielding dose increments from 7% to 45%.
- Step time length: 10 minutes
- Plume simulation was produced continuosuly for 20 hours

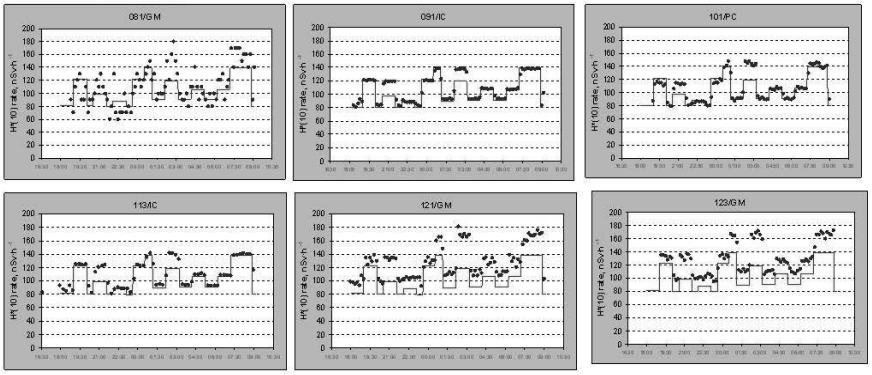


EURADOS 1998: Comparison of early warning instruments

(a) Instrumentos calibrados en términos de Dosis equivalente ambiental, H*(10)

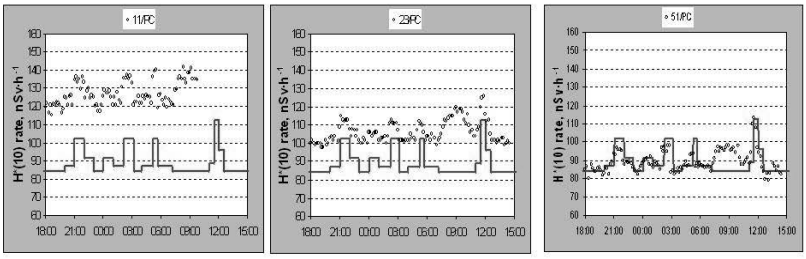


EURADOS 2002: Comparison of early warning instruments



THE PROBLEM

CONCLUSION: Relevant differences often occurs when comparing simultaneous environmental dose rate measruements!!



THE REASONS WHY

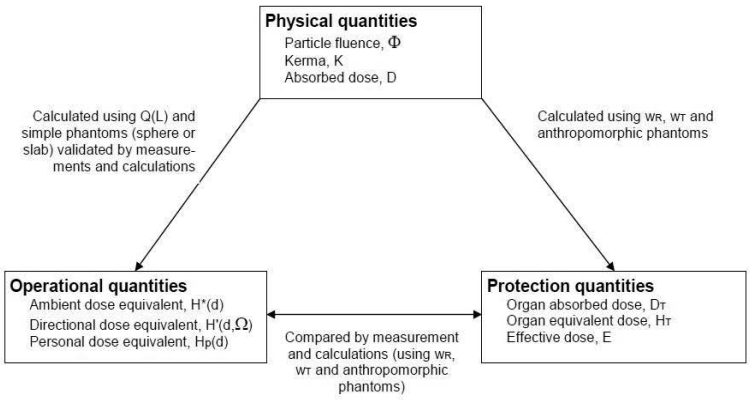
Why? Because accurate dose rate estimation is not so simply as:

Dose Rate = Signal x Calibration Factor

In fact, these are probably the most relevant factors affecting estimations:

- Quantity (and units!!!).
- Calibration conditions (procedure, reference energies, …)
- Sensitivity (time resolution).
- Inherent background.
- Photon Energy response.
- Cosmic Response.
- Angular Response.
- Environmental response (temperature, humidity, light…)

Quantities for external radiation dosimetry

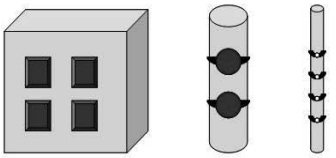


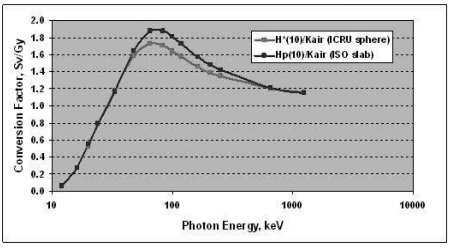
Quantities for external radiation dosimetry

-Absorbed Dose and Kerma are numerically equal in electronic equilibrium conditions: $D_m \cong K_m$

- Air Kerma and Exposure relationship is almost independent of photon energy. $X = K_{aire} \cdot (1 - g_{aire}) \cdot \left(\frac{e}{W}\right)$

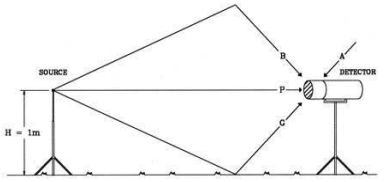
- Conversion Factors are needed to relate Air Kerma and Equivalent Dose quantities.

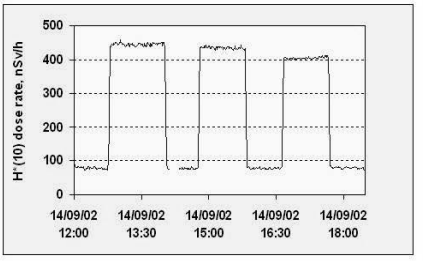




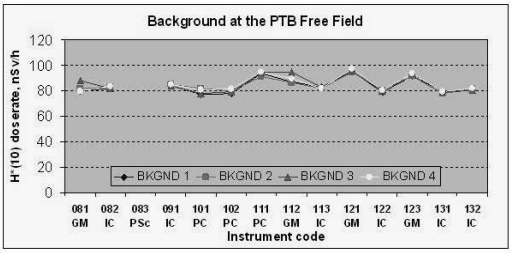
Free Field: Background and Calibration

- ^{137}Cs, ^{60}Co and ^{226}Ra encapsulated sources
- Reference distance: 5 m
- H*(10) rates: 330-400 nSv/h
- Reference values calculated by Reference instrument and MonteCarlo methods

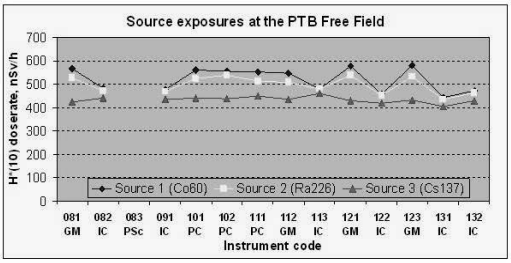




Results: Calibration Check



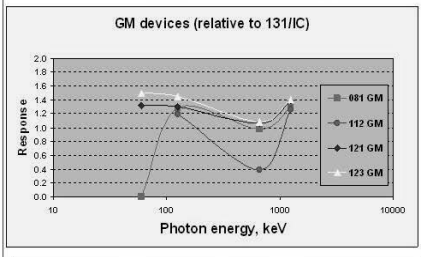
84.0±5.9 nSv/h (7%)
84.5±5.0 nSv/h (6%)
85.7±6.6 nSv/h (8%)
85.5±6.1 nSv/h (7%)

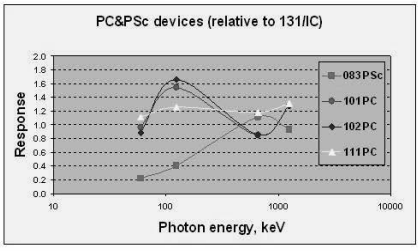


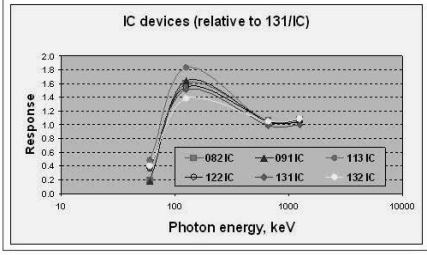
Co60: 520±48 nSv/h (9%)
Ra 226: 496±35 nSv/h (7%)
Cs137: 433±13 nSv/h (3%)

H*(10) Photon energy response

NOTE: Experimental inherent background has been substracted



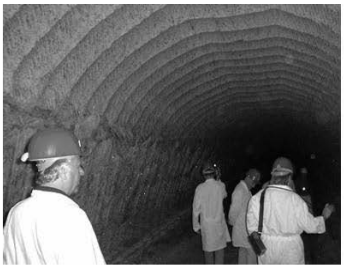


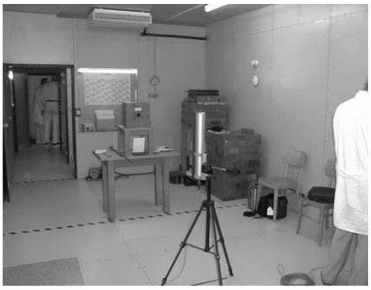


- Important over-response figures for GM and PC when dealing with ^{60}Co and ^{226}Ra
- Slight but consistent differences have been encountered for Reuter-Stokes HPIC

PTB UDO Ultra-low facility

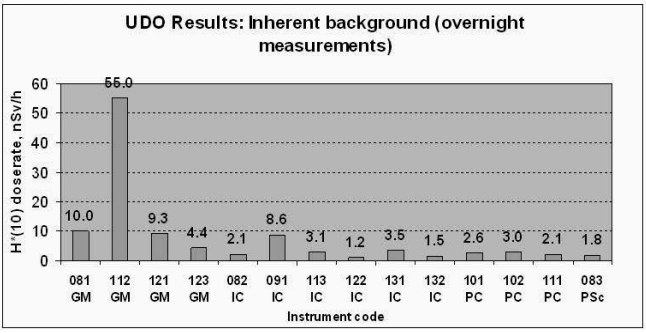
- Located 925 m depth in the Asse Salt Mine (Germany)
- Rock Salt Activity (Bq/kg): 2-4 (^{40}K), <0.1 (^{238}U), <0.01 (^{232}Th)
- H*(10) doserate: ≈ 1 nSv/h
- Excellent room conditions and irradiation facilities (collimated beams)



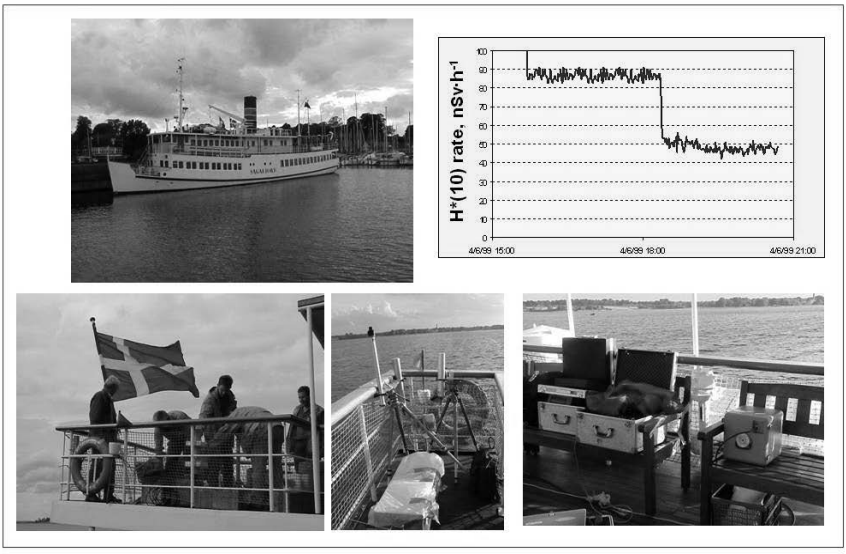


Collimated beams exposures and Inherent background measurements at UDO PTB

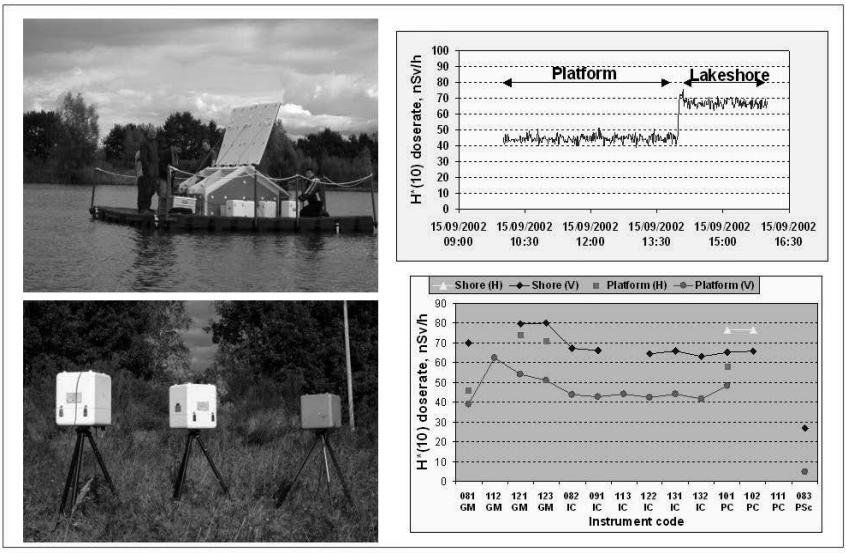
- ^{241}Am, ^{57}Co, ^{137}Cs, ^{226}Ra and ^{60}Co encapsulated sources (60-1300 keV)
- Reference distance: 2 m
- Kair rates: 30-130 nGy/h
- Inherent background was obtained after overnight exposure without any radioactive source.



Measurement of the cosmic radiation



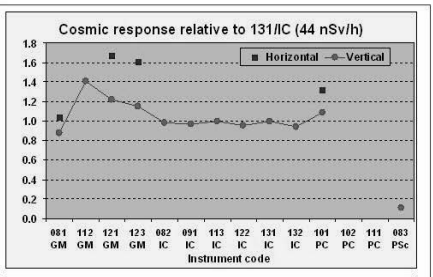
Cosmic&Terrestrial components (1/2)

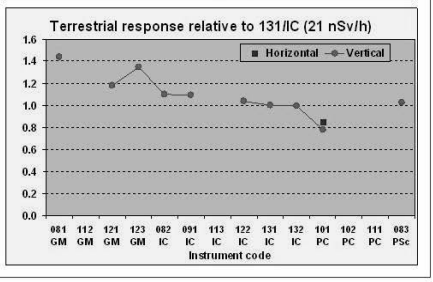


Cosmic&Terrestrial components (2/2)

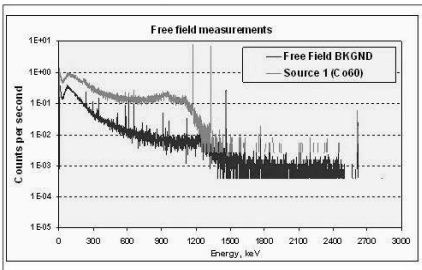
Reference levels for cosmic & terrestrial

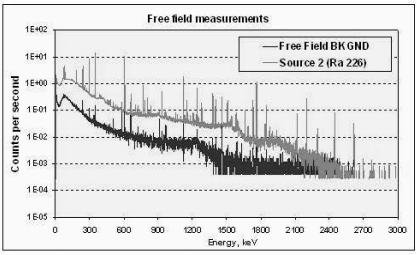
- Muon doserate at PTB-Braunschweig (PTB coincidence PC instrument): **34 nSv/h**
- Soft cosmic component (e^-, photons) is 30-40% of muon contribution (fluence): **10-13 nSv/h** totalising **44-47 nSv/h**
- Doserate at the platform from the Reference instrument 131/IC: **44 nSv/h**
- Reference level for terrestrial component (by difference Lakeshore-Platform): **21 nSv/h**

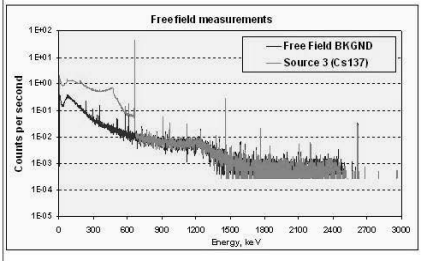




In situ Gamma Spectrometry



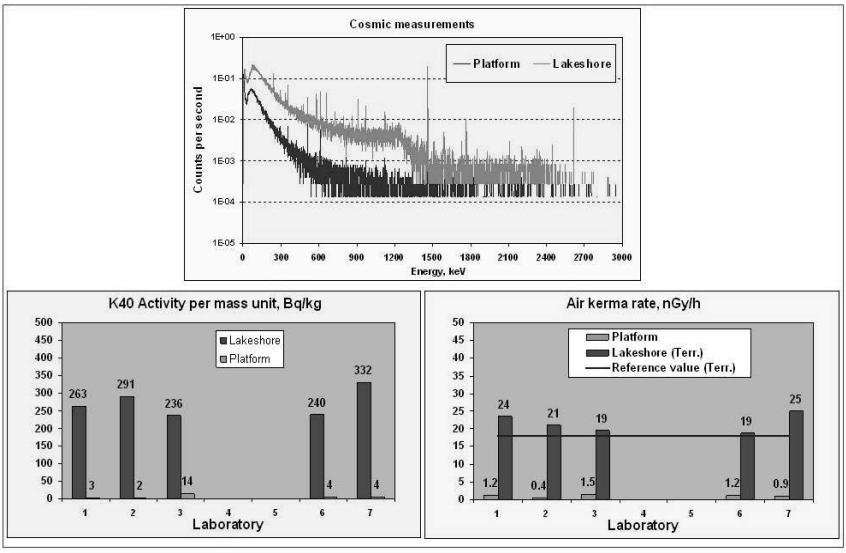




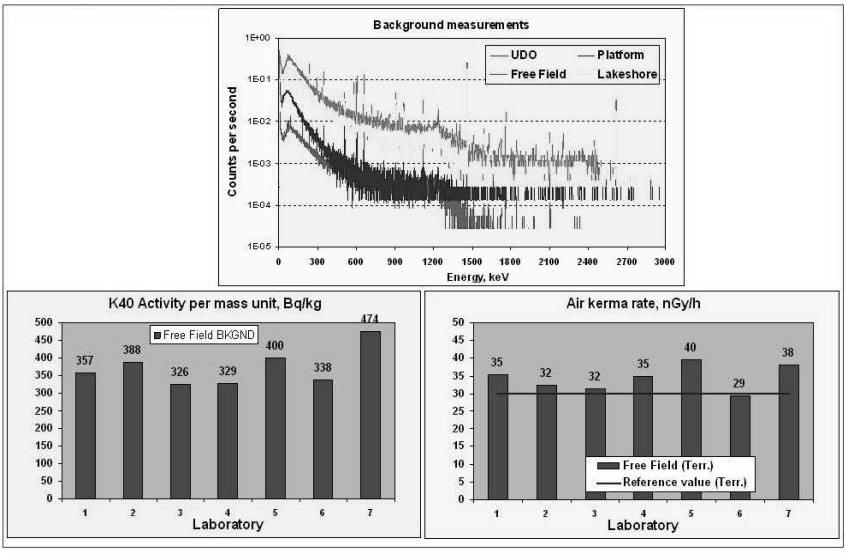
Reference levels for spectrometers

- Estimate of point source activity: Nominal source activity
- Other field measurements (no sources): Homogeneous nuclide distribution, Semi-infinite half space
- Air kerma rate from the direct beam (scattered radiation is not included)
- Values based on reference instrument (131/IC) measurements

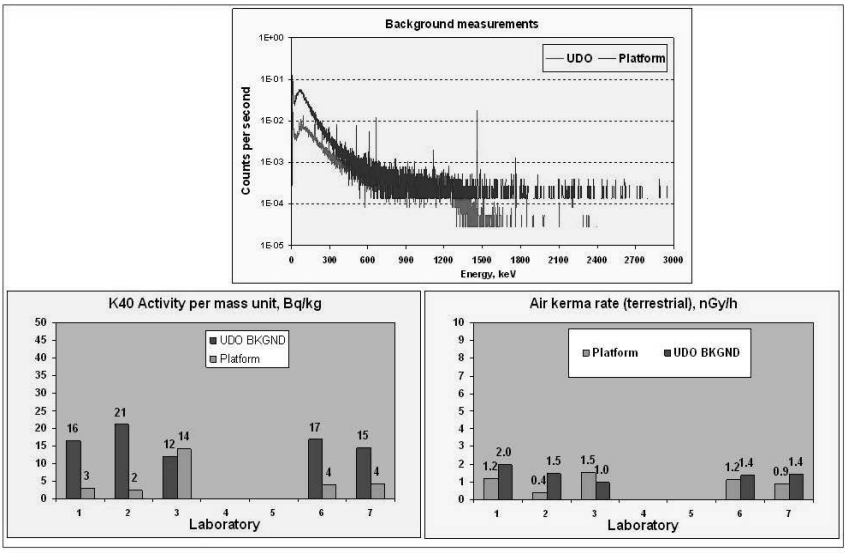
In situ gamma spectrometry



In situ gamma spectrometry



In situ gamma spectrometry



CONCLUSION

Dose Rate = f(Signal, Quantity, Calibration, BKGND, Cosmic, Photon Energy, Angular, others)

You should read the indications of your dose rate monitor and then apply the corresponding corection factors according to the field conditions.

Realistic calibration fields for environmental Dose rates and in situ gamma spectrometry

Wismuth GMBH, Gera, Germany

Cosmic & Terrestrial Studies in … Santander!

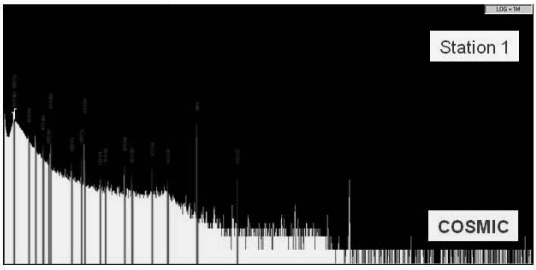
Resultados GENIE-2000/ISOCS ordenados por series

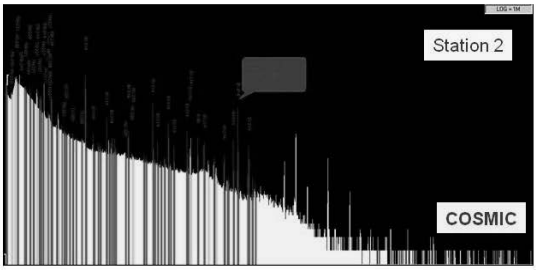
	Santander CMT Bq/kg	Santander Bahia Bq/kg	Aguilar Orilla Bq/kg	Aguilar Lago Bq/kg
Th-234	<AMD	<AMD	<AMD	<AMD
Pa-234m	<AMD	<AMD	<AMD	<AMD
Ra-226	79.3 ± 14.8	19.5 ± 5.5	28.9 ± 15.7	17.0 ± 8.4
Pb-214	34.1 ± 1.0	4.1 ± 0.4	21.1 ± 1.0	7.3 ± 0.5
Bi-214	37.1 ± 0.8	3.3 ± 0.2	22.8 ± 0.9	6.2 ± 0.5
Pb-210	<AMD	<AMD	<AMD	<AMD
Ac-228	34.0 ± 1.0	<AMD	17.4 ± 0.9	3.8 ± 0.4
Pb-212	31.7 ± 0.9	1.8 ± 0.4	17.1 ± 0.7	7.7 ± 0.6
Bi-212	31.3 ± 4.3	1.3 ± 1.2	22.2 ± 4.3	<AMD
Tl-208	13.3 ± 0.3	0.7 ± 0.1	6.9 ± 0.4	1.0 ± 0.1
K-40	391.7 ± 9.7	28.8 ± 1.6	383.4 ± 9.8	14.1 ± 1.6
Cs-137	0.4 ± 0.3	0.0 ± 0.0	8.8 ± 0.5	0.0 ± 0.0

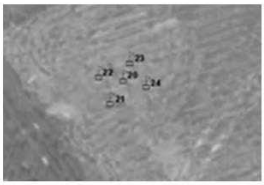
Resumen de tasa de kerma en aire

	Santander CMT 43° 29' N, 3° 48W 58 m nGy/h	Santander Bahia 43° 29' N, 3° 48W 0 m nGy/h	Aguilar Orilla 42° 47 ' N, 4° 2' W 970 m nGy/h	Aguilar Lago 42° 47' N, 4° 2' W 970 m nGy/h
Serie U-238	16.8 ± 0.4	1.6 ± 0.1	10.3 ± 0.4	2.9 ± 0.2
Serie Th-232	13.6 ± 0.5	0.3 ± 0.1	7.2 ± 0.5	1.4 ± 0.1
K-40	16.3 ± 0.4	1.2 ± 0.1	16.0 ± 0.4	0.6 ± 0.1
Cs-137	0.1 ± 0.1	0.0 ± 0.0	1.5 ± 0.1	0.0 ± 0.0
Terrestre SEGIS	46.8 ± 1.4	3.1 ± 0.3	34.9 ± 1.4	4.9 ± 0.4
Cósmica SEGIS	36.5 ± 2.8	37.1 ± 2.6	54.3 ± 3.6	55.4 ± 3.6
Cósmica CARI6	36.9	35.9	53.0	53.0
Total SEGIS	83.2 ± 3.1	40.2 ± 2.6	89.3 ± 3.8	60.2 ± 3.6
Total PIC	79.1 ± 0.9	40.1 ± 0.9	89.4 ± 0.9	52.8 ± 0.9
Cociente SEGIS/PIC	1.05 ± 0.05	1.00 ± 0.09	1.00 ± 0.05	1.14 ± 0.09

2011 Intercomparison at Saelices el Chico







2011 Intercomparison at Saelices el Chico

	Station 1 Bq/kg			Point 17 Bq/kg			Station 2 Bq/kg		
K-40	750	-	1150	600	-	900	750	-	1200
Th-234	< AMD			250	-	350	< AMD		
Pa-234m	< AMD			6	-	7	< AMD		
Ra-226	< AMD			700	-	800	5500	-	7500
Pb-214	30	-	40	220	-	230	4500	-	5500
Bi-214	30	-	50	210	-	250	4000	-	6000
Pb-210	< AMD			< AMD			2500	-	9500
Ac-228	15	-	30	30	-	40	40	-	80
Pb-212	15	-	20	30	-	40	50	-	100
Bi-212	25	-	30	50	-	80	< AMD		
Tl-208	5	-	10	15	-	20	10	-	30
U-235	< AMD			< AMD			< AMD		
Th-227	< AMD			< AMD			1300	-	2300
Ra-223	< AMD			< AMD			1400	-	2300
Cs-137	< AMD			< AMD			< AMD		

2011 Intercomparison at Saelices el Chico

	Zona	Estación 1	Estación 1	Estación 1	Estación 1	Estación 1	Estación 1	Estación 1
	Punto de medida	1	2	4	6	8		17
	X -UTM, m	701704.7	701707.3	701708.5	701700.9	701700.8	Promedio	701696.1
	Y-UTM, m	4501191.2	4501196.1	4501187.0	4501186.5	4501195.6	Puntos 1,2,4,6,8	4501238.9
	Z, m (snm)	719.3	719.1	719.1	720.0	719.1		719.8
	Notas							
CIP	Fecha de medida	25/04/2011	25/04/2011	25/04/2011	25/04/2011	25/04/2011	25/04/2011	25/04/2011
RSS-112	K_{aire}, nGy/h	111 ± 4	112 ± 4	110 ± 5	110 ± 4	107 ± 4	110 ± 2	173 ± 5
RSS-131	K_{aire}, nGy/h	112 ± 4	113 ± 5	110 ± 4	111 ± 4	105 ± 4	110 ± 3	174 ± 5

	Zona	Estación 2	Estación 2	Estación 2	Estación 2	Estación 2	Estación 2
	Punto de medida	20	21	22	23	24	
	X -UTM, m	701541.8	701539.6	701537.7	701542.8	701545.6	Promedio
	Y-UTM, m	4502440.1	4502436.4	4502440.6	4502442.9	4502439.0	Puntos 20 a 24
	Z, m (snm)	719.2	719.5	720.1	720.0	719.3	
	Notas						
CIP	Fecha de medida	26/04/2011	26/04/2011	26/04/2011	26/04/2011	26/04/2011	26/04/2011
RSS-112	K_{aire}, nGy/h	1862 ± 12	1831 ± 15	2008 ± 17	1901 ± 12	1815 ± 28	1883 ± 69
RSS-131	K_{aire}, nGy/h	1803 ± 66	1785 ± 67	2005 ± 31	1908 ± 30	1798 ± 68	1860 ± 85

Station 1 (Points 1 a 9): **0.110 ± 0.005 µGy/h (k=2)**
Point 17: **0.173 ± 0.005 µGy/h (k=2)**
Station 2 (Pointss 20 a 24): **1.80 ± 0.05 µGy/h (k=2)**

2011 Intercomparison at Saelices el Chico

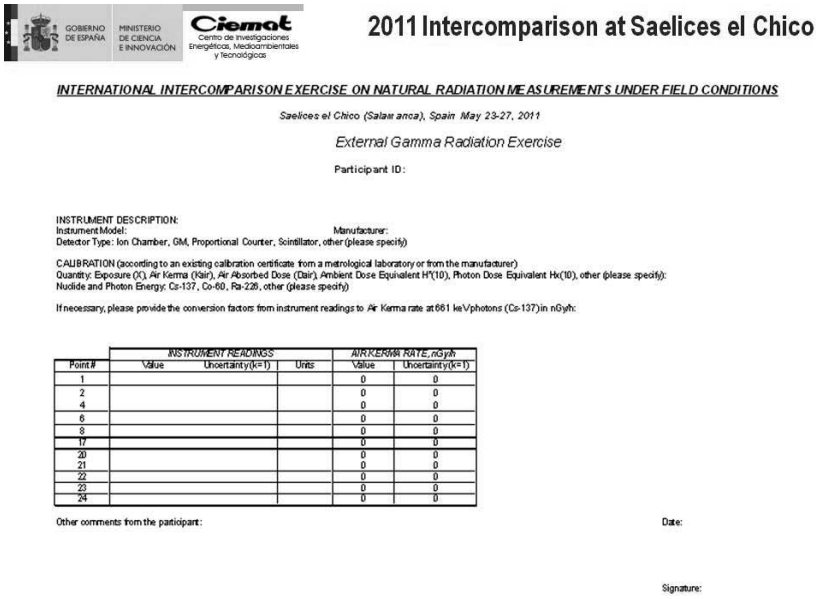
- In each station, please measure as many points as you can WITHIN the signals.

- 1.00 m high are indicated in some points.

- Results should be given in terms of air kerma. Conversion factors are given below.

- You should send a form per instrument, filled with all the requested information. PLEASE DON'T FORGET TO EXPRESS YOUR UNCERTAINTY.

Nuclide (Mean Photon Energy)	$H^*(10)/K_{air}$ Sv/Gy	H*(10)/X nSv/µR	K_{air}/X nGy/µR
^{241}Am (59.5 keV)	1.740	15.250	8.764
^{57}Co (122 keV)	1.447	12.683	8.764
^{137}Cs (661 keV)	1.200	10.517	8.764
^{226}Ra (840 keV)	1.179	10.336	8.764
^{60}Co (1.25 MeV)	1.160	10.166	8.764



INTERNATIONAL INTERCOMPARISON EXERCISE ON NATURAL RADIATION MEASUREMENTS UNDER FIELD CONDITIONS

Saelices el Chico (Salamanca), Spain May 23-27, 2011

External Gamma Radiation Exercise

Participant ID:

INSTRUMENT DESCRIPTION:
Instrument Model: Manufacturer:
Detector Type: Ion Chamber, GM, Proportional Counter, Scintillator, other (please specify)

CALIBRATION (according to an existing calibration certificate from a metrological laboratory or from the manufacturer)
Quantity: Exposure (X), Air Kerma (Kair), Air Absorbed Dose (Dair), Ambient Dose Equivalent H*(10), Photon Dose Equivalent Hx(10), other (please specify):
Nuclide and Photon Energy: Cs-137, Co-60, Ra-226, other (please specify)

If necessary, please provide the conversion factors from instrument readings to Air Kerma rate at 661 keV photons (Cs-137) in nGy/h:

	INSTRUMENT READINGS			AIR KERMA RATE, nGy/h	
Point #	Value	Uncertainty (k=1)	Units	Value	Uncertainty (k=1)
1				0	0
2				0	0
4				0	0
6				0	0
8				0	0
17				0	0
20				0	0
21				0	0
22				0	0
23				0	0
24				0	0

Other comments from the participant:

Date:

Signature:

4.2 List of participants

Table 6: List of participants IFC11 External gamma dose rate

Country	Institution
Belarus	Republic Center of Radiation Medicine and Human Ecology, Radiation Defence Laboratory
Czech Republic	RADON v.o.s.
Germany	SARAD
Hungary	University of Pannonia
Poland	Institute of Nuclear Physics PAN
Portugal	Laboratory of Natural Radioactivity, University of Coimbra
Romania	University Babes-Bolyai/Environmental Radioactivity and Nuclear Dating
Spain	Grupo de Física de las Radiaciones. Departamento de Física. Universidad Autónoma de Barcelona
Spain	Universidad de Extremadura. Badajoz
Spain	University of Extremadura. Caceres
Spain	Universidad de Las Palmas de Gran Canarias
Spain	CIEMAT

4.3 Results and discussion

Three areas were selected to carry out this exercise: Severiano's green (see Figure 5), point 17 and some points corresponding to high dose rate values. Each participant was evaluated according to the mean value given for each of the three zones. The mean values of all the participants are compared. A total number of 11 participants of the intercomparison decided to take part in this activity and they are listed in Table 6.

Figure 5: View of Severiano green

Figure 6 represents the results of all participants in the point called "Severiano green" together with the error bars. We can see in black the line corresponding to the average value of all the participants and in grey is represented the reference value provided by CIEMAT (which are listed in Table 7). 1SD (Standard deviation) up and down the average value are also represented in dashed lines. Table 7 shows the reference values in each sampling point determined by CIEMAT

Table 7: Reference values in the sampling points used in the exercise external gamma dose rate. The values are in units of Air Kerma Rate (nGy/h)

Point	Reference value
Severiano green	110
17	173
High gamma dose rate	1800

Only 7 equipments corresponding to the participants IFC11_02, IFC11_ 10, IFC11_ 18, IFC11_ 21, IFC11_ 29, IFC11_ 30 and IFC11_ 36 show values similar to the reference value in the point

Severiano green. Four of them are calibrated in Ambient Dose Equivalent H*(10) and three in Air Kerma. The rest of the participants give values inside the standard deviation of the mean value except participants IFC11_04, IFC11_06, IFC11_10, IFC11_ 20 and IFC11_ 30 which are out of this range. IFC11_04 and IFC11_06 used GM detectors. These devices are not suitable for low dose rates. In the case of IFC11_10 and IFC11_30 a Scintillator detector was utilized. IFC11_20 did not provide information about the type of detector used. On the other hand, the values are normally distributed in this point and the result of the ANOVA test showed that the values are comparable.

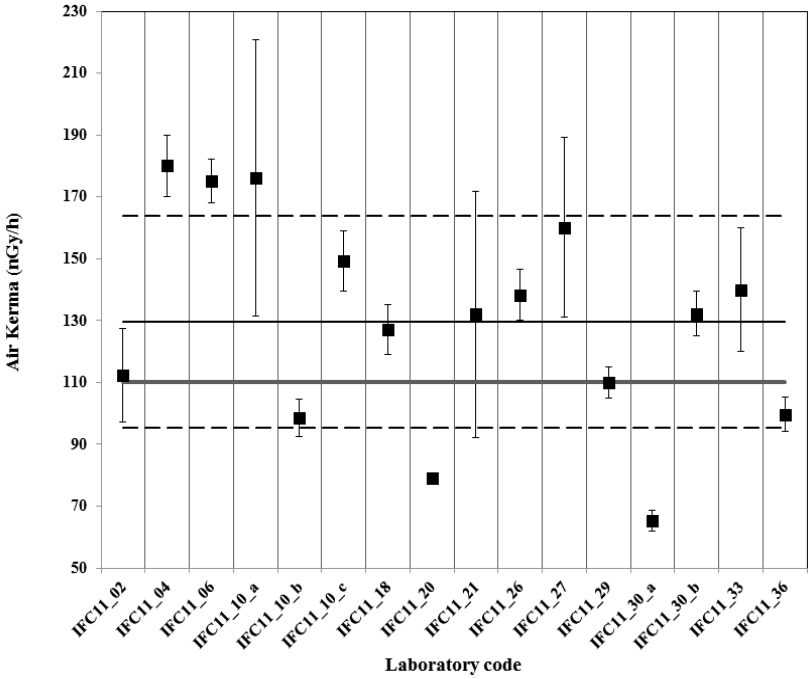


Figure 6 Results of external gamma radiation measured at the point Severiano green

The effect of temperature in the determination of external gamma dose rate was also studied. The laboratory IFC11_36 used proportional counter which indicated in its report that the sensor of high temperatures gave alarm during the exercise which means that this device is not suitable for outdoors measurements. The other three devices are INa(Tl) detectors and they present calibration errors. These four extra measurements are shown in Figure 7.

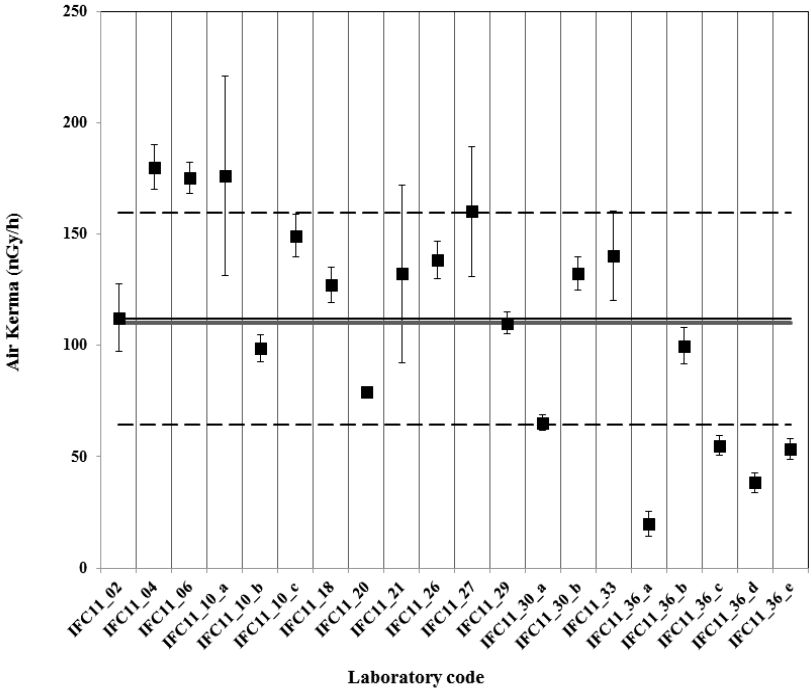


Figure 7 Data obtained in Severiano green with extra measurements carried out by laboratory IFC11_36. Four data from this laboratory are outside limits of standard deviation. These detectors are not suitable for low gamma dose rate determinations.

In the point marked as *point 17* only devices corresponding to the participant IFC11_10, IFC11_20, IFC11_26, IFC11_29 and IFC11_ 36 gave results close to the reference value. The rest of participants are inside the SD from the reference value except IFC11_04, IFC11_6 and IFC11_27. IFC11_04 and IFC11_27 have the same error as in the previous case and the error in the case of IFC11_27 was smaller than the equipment's device. We can see all the results for this point represented in Figure 8. As well as in the previous point, the values are normally distributed although in this case the ANOVA test shown that these values are not comparable.

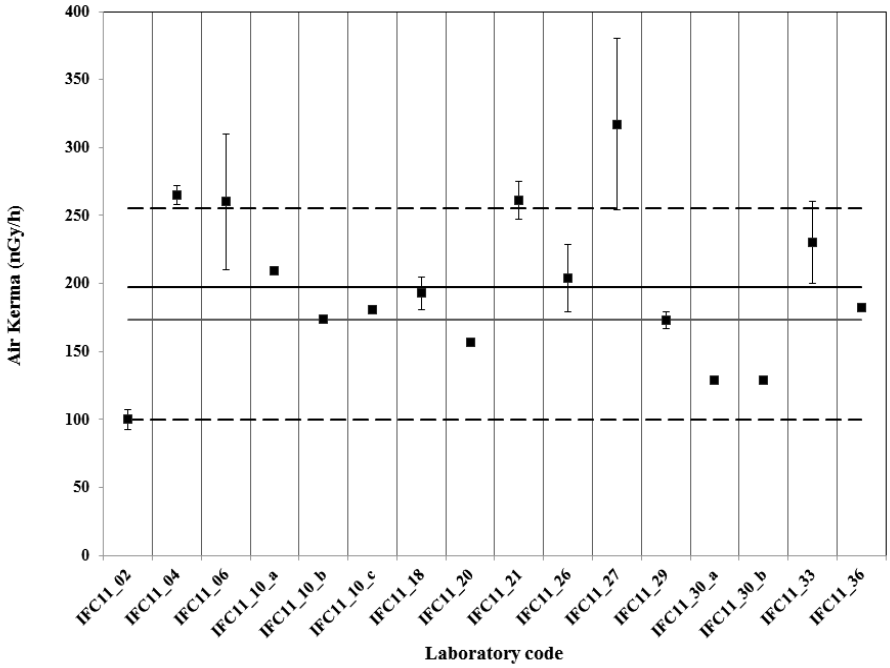


Figure 8 Results of external gamma dose rate in point 17. Black and grey lines represent mean and reference values respectively. Standard deviation up and down those values are in dashed black lines

Figure 9 shows the results of the measurements for the points with high dose rate. Most of the participants obtained results similar to the reference value in the case of high dose rate points. Only IFC11_21 and IFC11_30 are out the range of standard deviation from the average values. In the case of IFC11_21 a Scintillator INa(Tl) was used with a poor energy response. For high dose rates, high energy photons are quite important and the spectrum can be different comparing to the two previous points (*Severiano green* and *point 17*) and as a consequence the measurement's error is higher. The values in this case show a normal distribution and are comparable according to the ANOVA test.

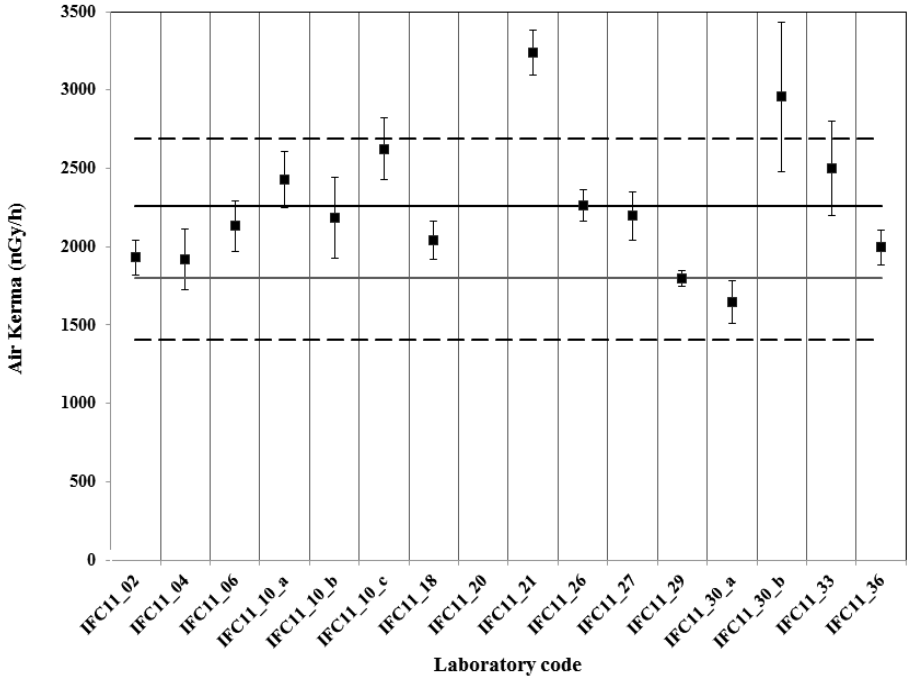
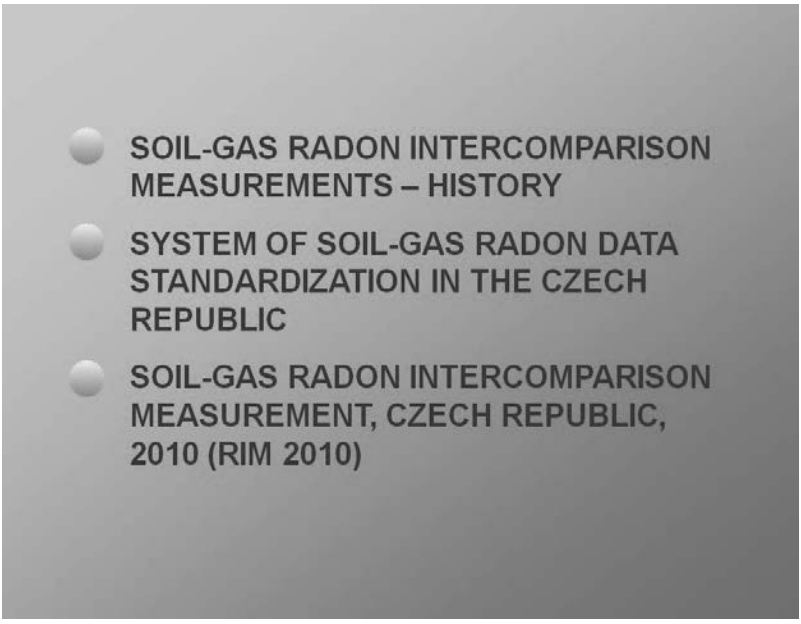


Figure 9 Results of external gamma dose rate in a point with high values of the parameter. Black and grey lines represent mean and reference values respectively

We can conclude that it has been observed the need to take into account the energy response of the detector in the case of ambient dose rate determinations. In these type of measurements, the energy spectrum is quite different from that use in the calibration of the device (normally a ^{137}Cs source). Most of the errors are due to this phenomenon. In a few number of cases the error is due to wrong calibration of the device. In these cases the device is not designed for outdoors determinations where the presence of natural radionuclides is significant.

5 Radon in soil gas

5.1 Introductory keynote given by Martin Neznal and Matej Neznal



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

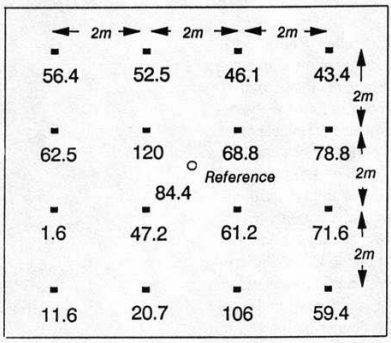


Fig. 1. Spatial variability of soil-gas radon concentration ($kBq \cdot m^{-3}$), Badgastein, Austria, 1991.

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

xercise. The first graph value reported by each a single value, so the graph depicts the ratio an value obtained at EML nts. 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 rning 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

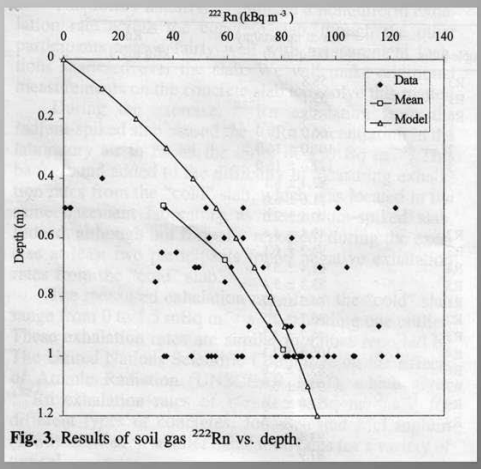


Fig. 3. Results of soil gas ^{222}Rn vs. depth.

Prague, Czech Republic, 1996

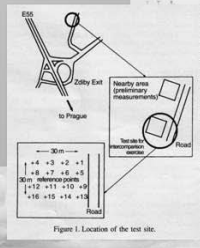


Figure 1. Location of the test site.

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

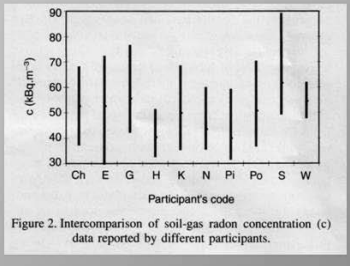


Figure 2. Intercomparison of soil-gas radon concentration (c) data reported by different participants.

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

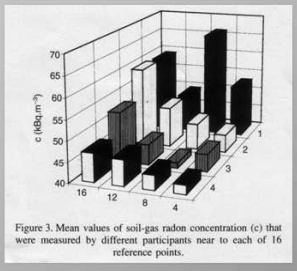


Figure 3. Mean values of soil-gas radon concentration (c) that were measured by different participants near to each of 16 reference points.

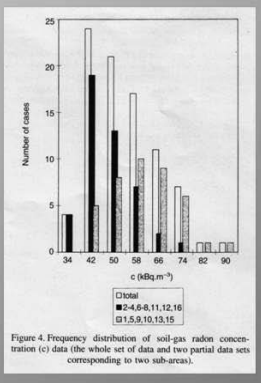
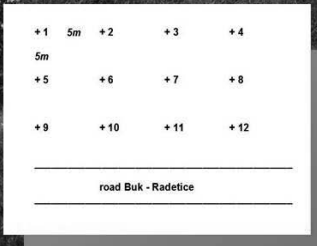


Figure 4. Frequency distribution of soil-gas radon concentration (c) data (the whole set of data and two partial data sets corresponding to two sub-areas).

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



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:

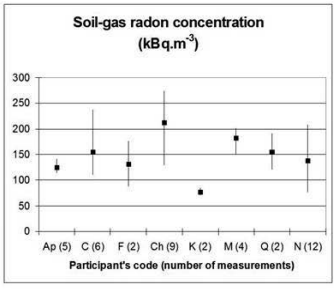


Figure 3. Intercomparison of soil-gas radon concentration data reported by different participants.

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:

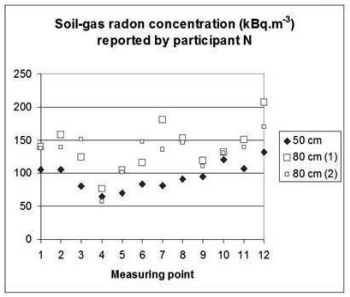


Figure 4. Soil-gas radon concentration data reported by participant N - temporal variations and changes with depth.

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)

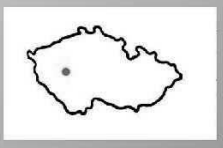
- Verification of instrument, its function, sensibility and calibration,
- Verification of data processing.

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

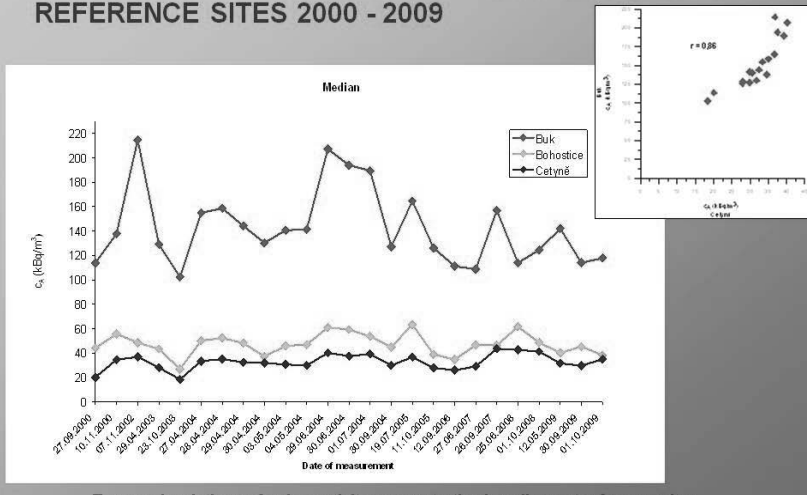


Radon reference sites
Number of stations at each site: 15
Grid of stations: 5x5 m
Distance of the 3 reference sites: 12 km

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	+

Charles University in Prague

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>

Charles University in Prague

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

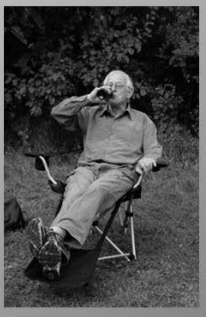
Seal

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).

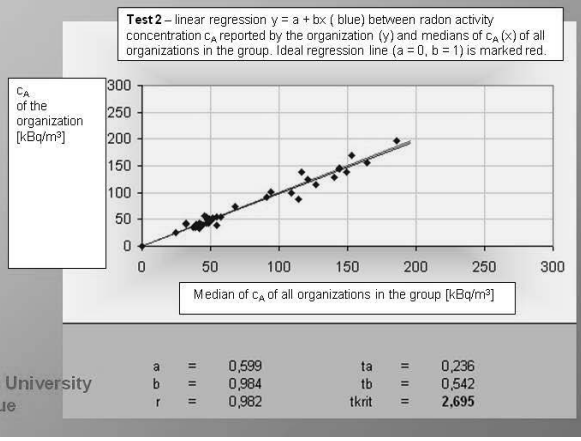
RIM 2010

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.



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

Charles University in Prague

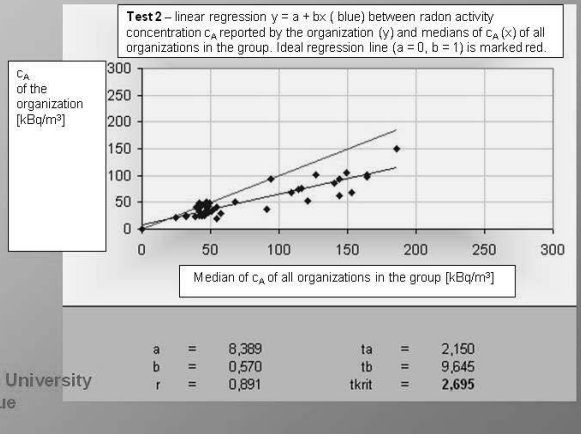
RIM 2010

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



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

Charles University in Prague

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

Charles University in Prague

Thank you

5.2 List of participants

Table 8: List of participants in IFC11 corresponding to the exercise Radon in soil

Country	Institution
Belgium	Federal Agency for Nuclear Control
Czech Republic	RADON v.o.s.
Germany	SARAD
Hungary	University of Pannonia
Italy	Dipartimento di Scienze Ambientali – Seconda Università di Napoli
Italy	Mi.am srl
Italy	Università Federico II
Norway	NRPA (Norwegian Radiation Protection Authority)
Poland	Institute of Nuclear Physics PAN
Portugal	Laboratory of Natural Radioactivity, University of Coimbra
Romania	University Babes-Bolyai/Environmental Radioactivity and Nuclear Dating
Slovenia	Jožef Stefan Institute, Department of Environmental Sciences, Radon Center
Spain	Grupo de Física de las Radiaciones. Departamento de Física. Universidad Autónoma de Barcelona
Spain	Universidad de Extremadura. Badajoz
Spain	Universidad de Las Palmas de Gran Canarias
Spain	LI2GA
Sweden	Gammadata Instruments

5.3 Characteristics of the radon detectors in soil gas used in the intercomparison

Participants were asked to provide together with the results information of the characteristics of their detection systems. The information on the method used is composed by two parts: description of the sampling system and description of the instrument utilized for obtaining the value of radon in soil gas.

The description of the sampling system includes: the type and description of the sampling probe (Neznal probe, packer probe, etc. …) and length of the probe, inner and outer diameter of the probe if available; description of the sampling system (syringe (grab sampling), pump and its parameters if available); typical volume of soil gas sampled. Concerning the information about the instrument, the next information was asked: Model of the instrument, Manufacturer, data of the last calibration and principle of measurement (type of the detector (scintillation cell, ionization chamber, other) and its parameters, measurement mode (for example delay between the soil-gas sample transfer into the detector and the beginning of counting; time of counting), thoron influence). Some participants also included a picture of their sampling system and the instrument. Therefore Table 9 contains the characteristics of the detection system of the participants in this exercise:

Table 9: Characteristics of the sampling system and instruments used in the exercise Radon in soil gas

IFC11_03	
SAMPLING SYSTEM DESCRIPTION	
Type (description) of the sampling probe	Neznal probe
Description of the sampling system	syringe
Typical volume of the soil-gas sample	150 ml
INSTRUMENT DESCRIPTION	
Instrument Model	LUK3A
Manufacturer	Plch SMM
Last calibration	04/08/09
Principle of measurement	lucas-cell scintillator, thoron estimated from ratio first/subsequent measurement
IFC11_04	
SAMPLING SYSTEM DESCRIPTION	
Type (description) of the sampling probe	Neznal probe
Description of the sampling system	grab sampling - syringe (150 ml)
Typical volume of the soil-gas sample	100 ml
INSTRUMENT DESCRIPTION	
Instrument Model	scintillometer: LUK 4A (J.P.057); glass-type Lucas cells (125 ml)
Manufacturer	scintillometer: SMM - Ing. Jiri Plch, Praha; Lucas cells: own production (RADON v.o.s.)
Last calibration	27/07/10
Principle of measurement	scintillation method; counting in equilibrium (more than 3,5 h after sampling); time of counting: 400 s; influence of thoron eliminated
IFC11_06	
Requested information was not provided	
IFC11_10	
SAMPLING SYSTEM DESCRIPTION	
Type (description) of the sampling probe	length of probe: 105 cm (50 cm was inserted into the soil) tightness was not taken into consideration direct insertion (no drilled hole); outer diameter: 1,2 cm; inner diameter: 0,8 cm;
Description of the sampling system	Alphaguard pump; air flow: 1 l/min
Typical volume of the soil-gas sample	0.56 l
INSTRUMENT DESCRIPTION	
Instrument Model	Alphaguard
Manufacturer	Genitron
Last calibration	18/11/10
Principle of measurement	Detector type: ionization chamber; Measurement mode: delay between the soil-gas sample transfer into the detector 5 min --> result: average of at least 10 minutes; Thoron influence was not eliminated
IFC11_11	
SAMPLING SYSTEM DESCRIPTION	
Type (description) of the sampling probe	Neznal probe (6*5 minutes pumping from soil)
Description of the sampling system	1 l/m pumping through the detector for on-line analysis
Typical volume of the soil-gas sample	5 l for each run (30 l total)
INSTRUMENT DESCRIPTION	

Instrument Model	Ramona 2.0
Manufacturer	Sezione di Napoli of the Italian National Institute of Nuclear Physics
Last calibration	Intercomparison for radon measurements in soil, Prague, 2010
Principle of measurement	Alpha spectrometry of radon daughters collected on a silicon detector
IFC11_13	
SAMPLING SYSTEM DESCRIPTION	
Type (description) of the sampling probe	MODEL GND100. Lenght 1 meter, external diam. 14 mm, internal diam 10 mm. Probe inserted directly in soil.
Description of the sampling system	Continuous sampling by monitor MR1 internal pump, flow approx. 0,25 LPM
Typical volume of the soil-gas sample	after 12 minutes approx 3 litres are fluxed through the cell
INSTRUMENT DESCRIPTION	
Instrument Model	MR1
Manufacturer	TESYS, ITALIA
Last calibration	April 2011, MIAM calibrated, traceable to NIST
Principle of measurement	SCINTILLATION CELL. Continuous flow through the cell. Counting interval 1 minute. Is taken an average value over 3 minute counts, after 12 minutes sampling. Value is corrected for radon daughters equilibrium
IFC11_16	
SAMPLING SYSTEM DESCRIPTION	
Type (description) of the sampling probe	Neznal probe (6*5 minutes pumping from soil)
Description of the sampling system	1 l/m pumping through the detector for on-line analysis
Typical volume of the soil-gas sample	5 l for each run (30 l total)
INSTRUMENT DESCRIPTION	
Instrument Model	Ramona 2.0
Manufacturer	Sezione di Napoli of the Italian National Institute of Nuclear Physics
Last calibration	Intercomparison for radon measurements in soil, Prague, 2010
Principle of measurement	Alpha spectrometry of radon daughters collected on a silicon detector
IFC_17	
SAMPLING SYSTEM DESCRIPTION	
Type (description) of the sampling probe	No information
Description of the sampling system	No information
Typical volume of the soil-gas sample	No information
INSTRUMENT DESCRIPTION	
Instrument Model	MARKUS 10
Manufacturer	Gammadata
Last calibration	Nov-09
Principle of measurement	Pumping soil air into a chamber. The detector registers the pulses from polonium 218.
IFC_18	
SAMPLING SYSTEM DESCRIPTION	
Type (description) of the sampling probe	Soil Gas Probe for AlphaGUARD Soil Gas Monitor
Description of the sampling system	AlphaPUMP (Genitron), 0.5 dm3/min), 20 min. of pumping
Typical volume of the soil-gas sample	ca. 10 dm3
INSTRUMENT DESCRIPTION	
Instrument Model	AlphaGUARD PQ 2000PRO
Manufacturer	Genitron
Last calibration	19/04/2006, yearly checking in radon chamber

Principle of measurement	ionization chamber, thoron eliminated by decay time
IFC11_20	
SAMPLING SYSTEM DESCRIPTION	
Type (description) of the sampling probe	65cm dual probe (circulation), inserted in a 2cm drilled hole
Description of the sampling system	Pump, 1l/m
Typical volume of the soil-gas sample	20 l
INSTRUMENT DESCRIPTION	
Instrument Model	Alphaguard Pro
Manufacturer	Saphymo-Genitron
Last calibration	15/05/2009 by the manufacturer - periodic verification in certified calibration chamber with NIST SRM-4974 Radon source
Principle of measurement	Ionization chamber
IFC11_21	
SAMPLING SYSTEM DESCRIPTION	
Type (description) of the sampling probe	No information
Description of the sampling system	No information
Typical volume of the soil-gas sample	No information
INSTRUMENT DESCRIPTION	
Instrument Model	LUK 3C
Manufacturer	Jiří Plch-SMM, Prague
Last calibration	from manufacturer
Principle of measurement	Lucas cell (scintillation)
IFC11_24	
SAMPLING SYSTEM DESCRIPTION	
Type (description) of the sampling probe	Soil gas sampling system with small-diameter hollow probe Neznal probe
Description of the sampling system	Soil gas pumped through scintillation cell for 1.5 min at a flow rate of 1 dm3 min–1
Typical volume of the soil-gas sample	0.31 dm^3
INSTRUMENT DESCRIPTION	
Instrument Model	PRM-145
Manufacturer	AMES, Slovenia
Last calibration	29/11/06
Principle of measurement	Scintillation cell counted after 3 hours, when radioactive equilibrium was reached, 3-times for 5 min
IFC11_26	
SAMPLING SYSTEM DESCRIPTION	
Type (description) of the sampling probe	STITZ-soil Gas probe (Exterior probe: 1 m length, inner diameter 1,2 cm and outer diameter 2,2 cm; Interior probe: 1 m length, inner diameter 0,2 cm and outer diameter 0,6 cm). We always hammer the exterior probe into the ground but in this test we have used previously drilled holes of 50 cm depth done by another participant with a drill of 2,5 cm diameter and then we hammered the probe the last 10 cm to assure the sampling system tightness.
Description of the sampling system	Using the AlphaPUMP to a performance of 1 Liter/min we fill a plastic bag with approx 1 liter capacity. Once the bag is full of air, we close up Alphaguard on two sides with taps.
Typical volume of the soil-gas sample	The active detector volume (0,56 liter)
INSTRUMENT DESCRIPTION	
Instrument Model	AlphaGUARD

Manufacturer	Saphymo GmbH
Last calibration	18/12/09
Principle of measurement	Ionization Chamber. In the 1-min flow mode we measure the soil-gas sample during 15 min. Later analysis allow us to distinguish radon and thoron concentrations.
IFC11_27	
SAMPLING SYSTEM DESCRIPTION	
Type (description) of the sampling probe	STITZ-Soil Gas Probe (AlphaGuard)
Description of the sampling system	AlphaPUMP to a performance of 1 Liter/min
Typical volume of the soil-gas sample	No information
INSTRUMENT DESCRIPTION	
Instrument Model	AlphaGuard PQ2000PRO
Manufacturer	Saphymo (GmbH)
Last calibration	27/10/10
Principle of measurement	Ionization chamber. Flow-mode-1 min. Without thoron
IFC11_29	
SAMPLING SYSTEM DESCRIPTION	
Type (description) of the sampling probe	Neznal probe
Description of the sampling system	grab sampling - syringe (150 ml)
Typical volume of the soil-gas sample	100 ml
INSTRUMENT DESCRIPTION	
Instrument Model	scintillometer: LUK 4A (J.P.057); glass-type Lucas cells (125 ml)
Manufacturer	scintillometer: SMM - Ing. Jiri Plch, Praha; Lucas cells: RADON v.o.s.
Last calibration	No information
Principle of measurement	scintillation method; counting in equilibrium (more than 3,5 h after sampling); time of counting: 400 s; influence of thoron eliminated
IFC11_30	
Requested information was not provided	
IFC11_40	
Requested information was not provided	
IFC11_43	
SAMPLING SYSTEM DESCRIPTION	
Type (description) of the sampling probe	No information
Description of the sampling system	No inform
Typical volume of the soil-gas sample	No inform
INSTRUMENT DESCRIPTION	
Instrument Model	MARKUS 10
Manufacturer	Gammadata
Last calibration	No information
Principle of measurement	Pumping soil air into a chamber. The detector registers the pulses from polonium 218

5.4 Results and discussion

The selected area for this exercise was previously analysed by the Czech company Radon v.o.s. It consisted in an area with high levels of radon in soil gas and several points were marked to perform the determinations. Figure 10 shows a picture of the working area for this exercise.

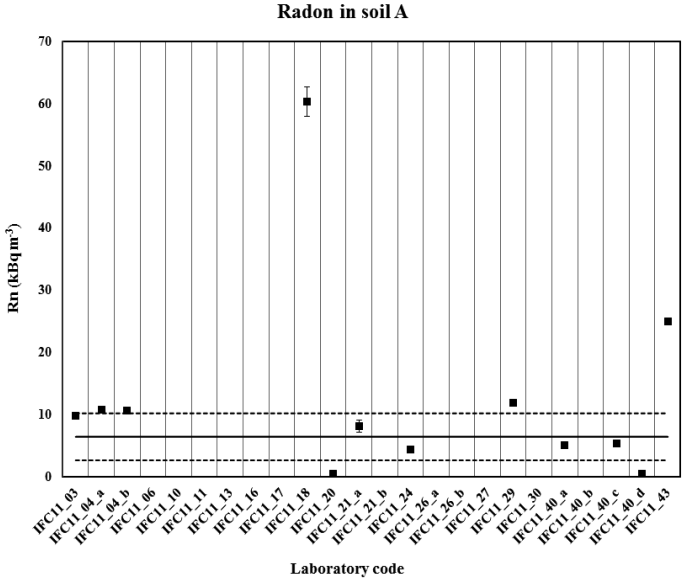
Each participant was asked for results in terms of kBq m^{-3} of radon in soil gas. In addition, other parameters were also necessary in order to interpret the results: Depth below the ground surface (cm), Time of the soil-gas sampling collection (s), Volume of the soil-gas sampling (l) and the uncertainty of the measurement. There was a limitation on the time for this exercise thus not all the participants measured in all the points. Table 10 shows the radon in soil in those points where at least 11 data are available. There are data corresponding to other points located between the points from Table 10 but the results are not representative due to the low number of laboratories which performed the measurements in those points. However, Appendix II includes these extra points in a further analysis of the results from this exercise. The distribution of the results in each point was checked and two different data distribution was found. First, in points A, B, D, F and H the values follow a log-normal distribution and the mean value is obtained in terms of Geometric Mean and deviation correspond to the Geometric Standard deviation. In the particular case of point D the log-normal distribution is obtained if we subtract the results of participants IFC11_18 and IFC11_43 whose results for this point are quite different from the rest of laboratories. On the second hand, the distribution of the rest of the points C, E and G is normal and the results are characterized by mean and standard deviation.

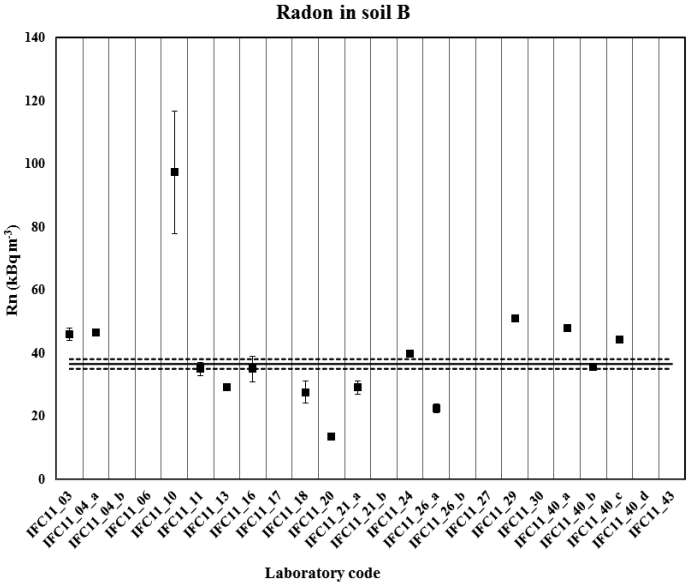
Figure 10: Working area selected for the exercise radon in soil

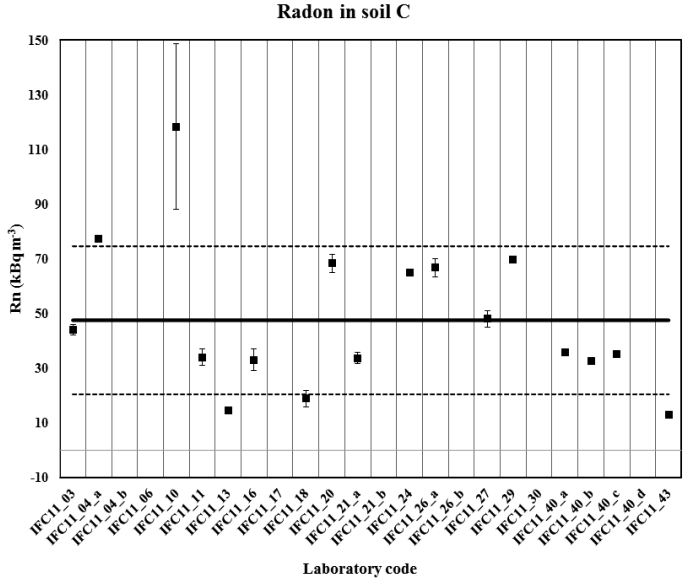
Table 10: Mean values of radon in soil gas in some points of the study area. All the values are in kBq m^{-3}.

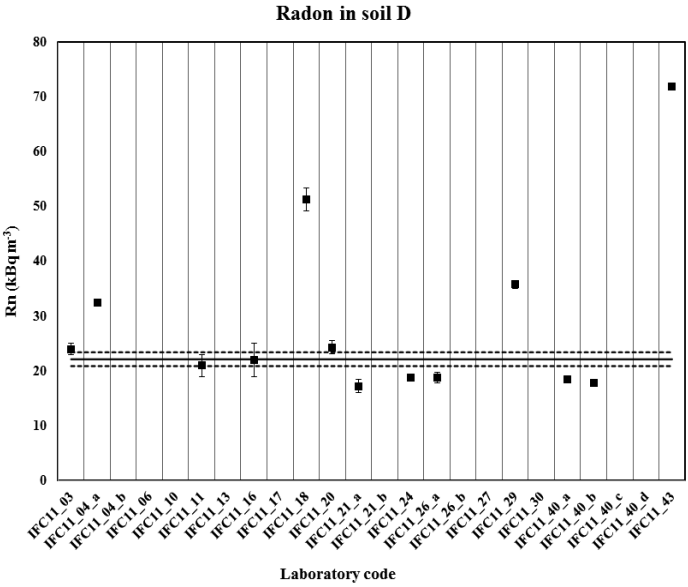
Point	Radon in soil gas	Deviation
A	13	16
B	40	19
C	48	27
D	29	16
E	72	36
F	37	39
G	126	94
H	22	8

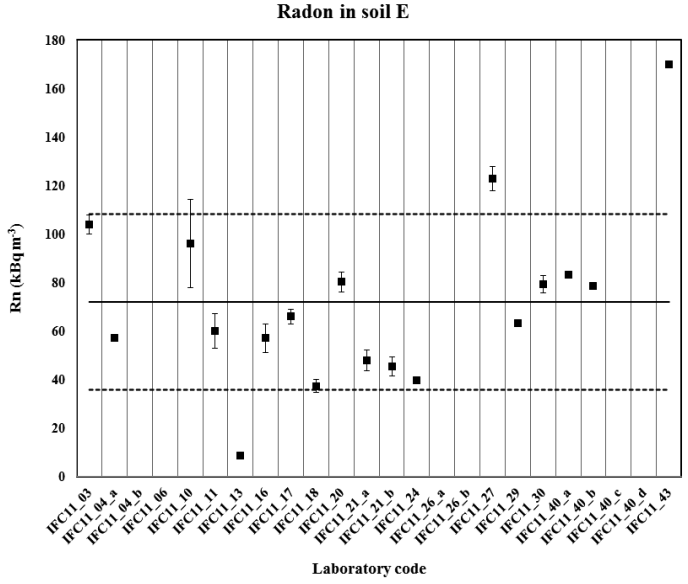
It is interesting to have a view of the results obtained in every point in order to check how dispersed all the results are. This is shown in Figure 11.

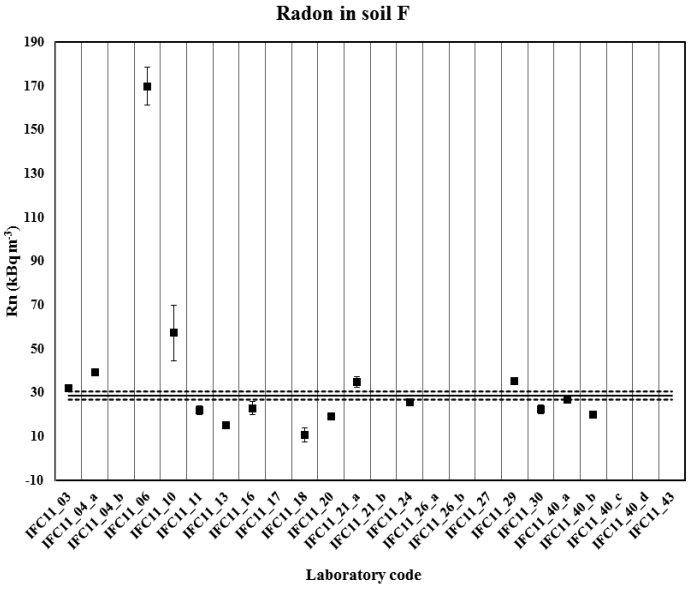


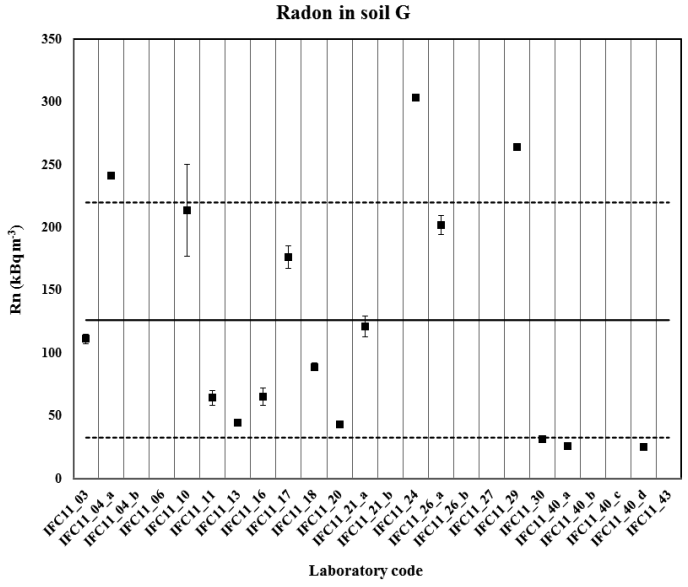

Radon in soil B
Rn (kBq m-3)
140
120
100
80
60
40
20
0
IFC11_03
IFC11_04_a
IFC11_04_b
IFC11_06
IFC11_10
IFC11_11
IFC11_13
IFC11_16
IFC11_17
IFC11_18
IFC11_20
IFC11_21_a
IFC11_21_b
IFC11_24
IFC11_26_a
IFC11_26_b
IFC11_27
IFC11_29
IFC11_30
IFC11_40_a
IFC11_40_b
IFC11_40_c
IFC11_40_d
IFC11_43
Laboratory code


Radon in soil C
Rn (kBq m-3)
150
130
110
90
70
50
30
10
-10
IFC11_03
IFC11_04_a
IFC11_04_b
IFC11_06
IFC11_10
IFC11_11
IFC11_13
IFC11_16
IFC11_17
IFC11_18
IFC11_20
IFC11_21_a
IFC11_21_b
IFC11_24
IFC11_26_a
IFC11_26_b
IFC11_27
IFC11_29
IFC11_30
IFC11_40_a
IFC11_40_b
IFC11_40_c
IFC11_40_d
IFC11_43
Laboratory code


Radon in soil D
Rn (kBq m-3)
0
10
20
30
40
50
60
70
80
IFC11_03
IFC11_04_a
IFC11_04_b
IFC11_06
IFC11_10
IFC11_11
IFC11_13
IFC11_16
IFC11_17
IFC11_18
IFC11_20
IFC11_21_a
IFC11_21_b
IFC11_24
IFC11_26_a
IFC11_26_b
IFC11_27
IFC11_29
IFC11_30
IFC11_40_a
IFC11_40_b
IFC11_40_c
IFC11_40_d
IFC11_43
Laboratory code


Radon in soil E
Rn (kBq m-3)
0
20
40
60
80
100
120
140
160
180
IFC11_03
IFC11_04_a
IFC11_04_b
IFC11_06
IFC11_10
IFC11_11
IFC11_13
IFC11_16
IFC11_17
IFC11_18
IFC11_20
IFC11_21_a
IFC11_21_b
IFC11_24
IFC11_26_a
IFC11_26_b
IFC11_27
IFC11_29
IFC11_30
IFC11_40_a
IFC11_40_b
IFC11_40_c
IFC11_40_d
IFC11_43
Laboratory code


Radon in soil F
Rn (kBq m-3)
190
170
150
130
110
90
70
50
30
10
-10
IFC11_03
IFC11_04_a
IFC11_04_b
IFC11_06
IFC11_10
IFC11_11
IFC11_13
IFC11_16
IFC11_17
IFC11_18
IFC11_20
IFC11_21_a
IFC11_21_b
IFC11_24
IFC11_26_a
IFC11_26_b
IFC11_27
IFC11_29
IFC11_30
IFC11_40_a
IFC11_40_b
IFC11_40_c
IFC11_40_d
IFC11_43
Laboratory code


Radon in soil G
Rn (kBq m-3)
350
300
250
200
150
100
50
0
IFC11_03
IFC11_04_a
IFC11_04_b
IFC11_06
IFC11_10
IFC11_11
IFC11_13
IFC11_16
IFC11_17
IFC11_18
IFC11_20
IFC11_21_a
IFC11_21_b
IFC11_24
IFC11_26_a
IFC11_26_b
IFC11_27
IFC11_29
IFC11_30
IFC11_40_a
IFC11_40_b
IFC11_40_c
IFC11_40_d
IFC11_43
Laboratory code

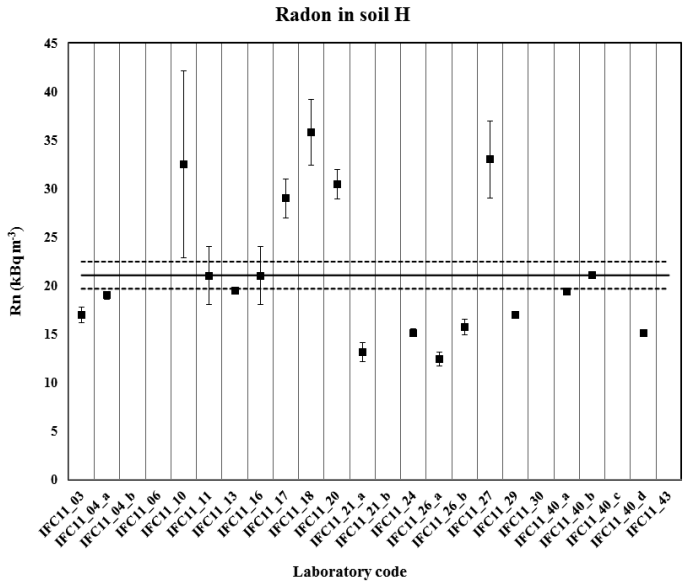


Figure 11 Graphs showing the results of participants in the points selected for radon gas in soil measurements

It is quite difficult to make an interpretation of the results due to the inhomogeneity of the values. However, we can extract some conclusions from the graphs showed above. Point A has the lowest radon in soil gas concentration (6 kBq m^{-3}) according to the geometric mean of the participants in this point. This is also the point with the lowest number of measurements. In this point the laboratories IFC11_18 and IFC11_43 gave a value quite different from the rest of the participants. Most of them are inside the limits indicated by geometric standard deviation respected geometric mean value and IFC11_21 and IFC11_40 obtained a result quite similar to the mean value. On the other side, the point H has the biggest number of results (19) but most of these values are outside the limits marked by one Geometric Standard deviation from the Geometric mean. Only three laboratories provided a value similar to the geometric mean for this point. The point with the biggest radon gas in soil is G with a mean value of 126 kBq m^{-3}. There are 16 results available for this point and most of them are below mean value but still inside the bands pointed by standard deviation. Laboratories IFC11_04, IFC11_24, IFC11_29 and IFC11_40 obtained a result outside these limits. It is interested the result for the point F (29 kBq m^{-3} geometric mean). There are 3 participants with results different from the geometric mean value (IFC11_04, IFC11_06 and IFC11_10) and the rest of the results are very close to the geometric mean but outside the limits determined by geometric standard deviation from this value. The point E (72 kBq m^{-3}, mean value) presents a big dispersal from the mean value and three of the laboratories (IFC11_13, IFC11_27 and IFC11_43) are outside the limits of standard deviation from the mean value highlighting participant IFC11_43 with a value quite different from the others. The rest of the points (B, C and D) indicate a normal behaviour and we can remark that the participant IFC11_10 got different values from the rest of participants in the points B and C.

Finally we can analyse the distribution of the values of each participant for all the points. This analysis will allow us to characterize the working field in order to have a value representative of the radon gas in soil in all the area. There are 24 series of data some of them belong to the same laboratory. For the data distribution analysis only those series with values at least for 5 points were taken into account. Thence we can conclude that 9 of the series present a normal distribution of data and 6 are log-normally distributed. We can define a new parameter called *Radon gas in soil characteristic* (RGC) which is the mean value obtained by the participant in all the measurements performed in the working field. The way to calculate RGC will depend on the type of data distribution observed. The associated uncertainty will also depend on the type of distribution.

Table 11: Results of radon in soil gas according to the defined parameter RGC (Radon soil characteristic). All the values are given in kBq m^{-3}

Laboratory	RGC	Unc
IFC11_03	48	39
IFC11_04_a	44	2
IFC11_10	103	63
IFC11_11	37	18
IFC11_13	22	13
IFC11_16	37	18
IFC11_18	41	25
IFC11_20	35	27
IFC11_21_a	28	2
IFC11_24	32	3
IFC11_26_a	37	3
IFC11_29	44	2
IFC11_40_a	33	24
IFC11_40_b	30	2
IFC11_43	63	64

Table 11 shows the results for RGC in the working field. The laboratories highlighted in yellow are those which data distribution is log-normal and RGC is the geometric mean and Unc is the geometric standard deviation. It is interesting to note that laboratory IFC11_40 has normal and log-normal distribution of its data. We can represent these data to observe any trend as we do in Figure 12. The geometric mean of all the values is 39 kBq m^{-3} and the related geometric standard deviation is 1 kBq m^{-3}. Only laboratories IFC11_10 and IFC11_43 present a value of RGC clearly higher than the rest of the participants.

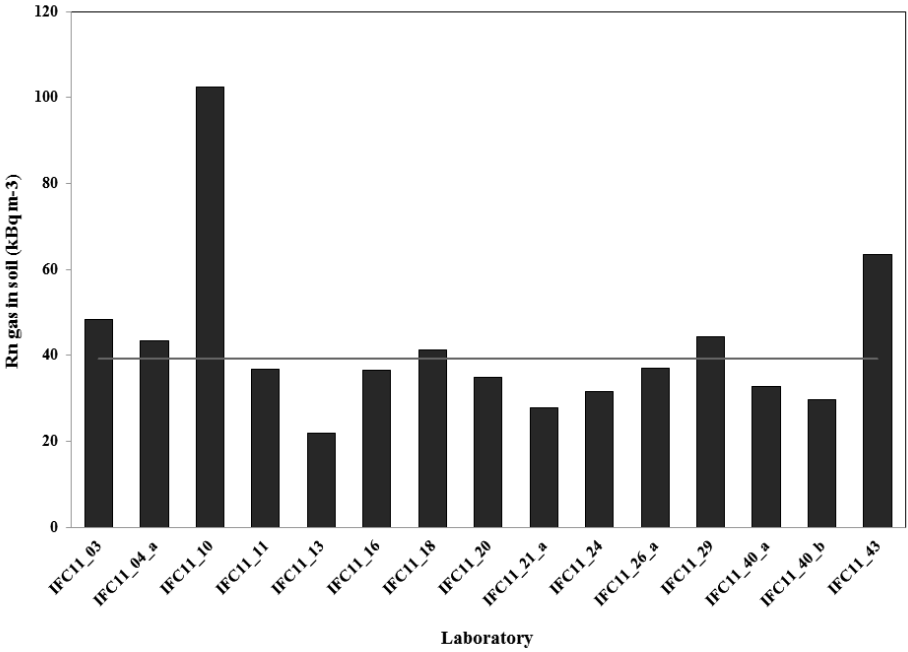
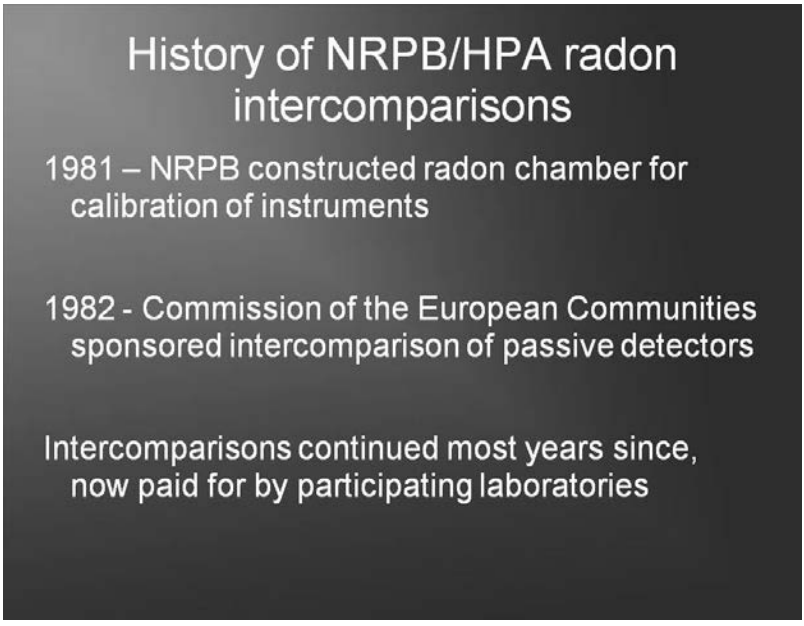


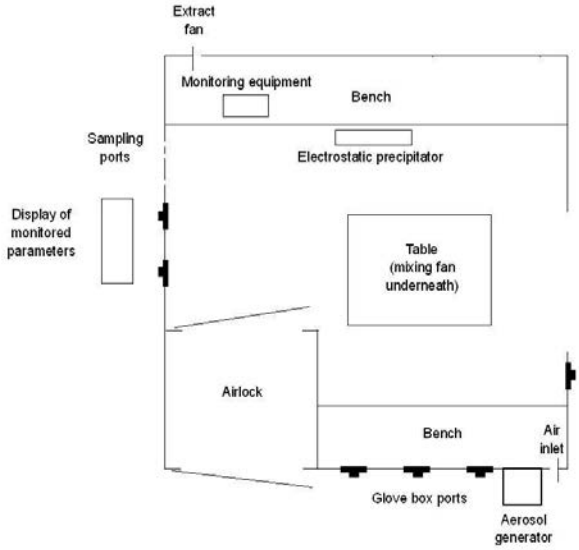
Figure 12 Values of RGC parameter which is used to characterize the working field used for radon gas in soil exercise. Grey line indicates the geometric mean of the data

6 Radon indoors passive detectors

6.1 Introductory keynote given by Jon Miles



HPA radon chamber



Parameters monitored and/or controlled

- Radon concentration
- Radon decay product concentrations (hence equilibrium factor)
- Temperature
- Pressure
- Humidity
- Radon-220 decay product concentrations
- Aerosol concentration/size distribution

Radon chamber characteristics

- Steady state (constant emanation) type
- Volume 43 m^3
- Radon concentration 400 – 8000 Bq m^{-3}
- Equilibrium factor (F) 0.1 – 0.9 (approximately)
- Unattached fraction (fp) up to 0.3
- Aerosol concentration 2000 – 70 000 particles cm^{-3}, MTD 90 -120 nm
- Temperature, pressure, humidity monitored but not controlled

Equilibrium factor (F)

F controlled by use of aerosol generator and electrostatic precipitator

Exposures carried out at low, medium and high F

Results show that closed detectors not affected, open LR-115 detectors have response closer to radon exposure than EER exposure

Neutron response

Two intercomparisons included exposure to a simulated cosmic field, to determine neutron sensitivity

2001 and 2003

Detectors exposed in pairs at CERF, Switzerland

All detectors showed some response

Response was variable both between and within individual detector types and designs

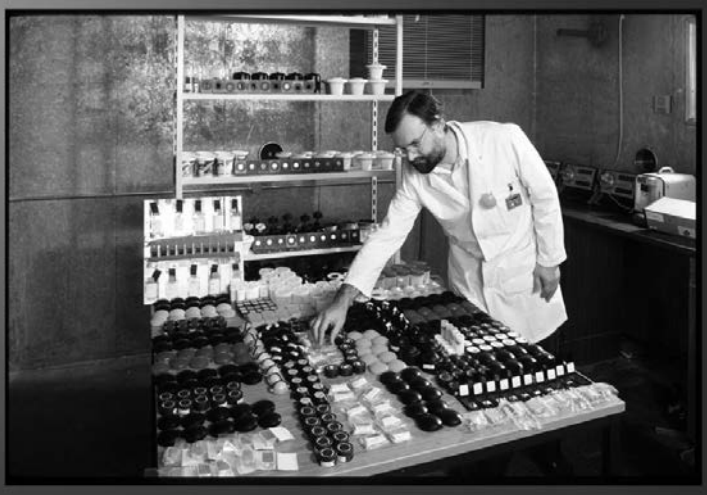
Non-laboratory exposures

Some intercomparisons included extra non-laboratory exposures, to determine whether there are any extra problems in home exposures

- 1982 exposure in NRPB office
- 1984 exposure in UK home
- 1987 exposure in UK home
- 1995 exposures in Italian, Swedish and Luxembourg homes

Logistics of intercomparisons

- 40 detectors per laboratory, 10 transit and 10 for each of 3 exposures
- 30 detectors for exposure randomised
- 10 detectors from each laboratory exposed at the same time
- Participants don't know which detectors exposed together
- Participants report results before exposures are calculated
- Arrangements different for charcoal and electret



Packaging of detectors between exposures and for return

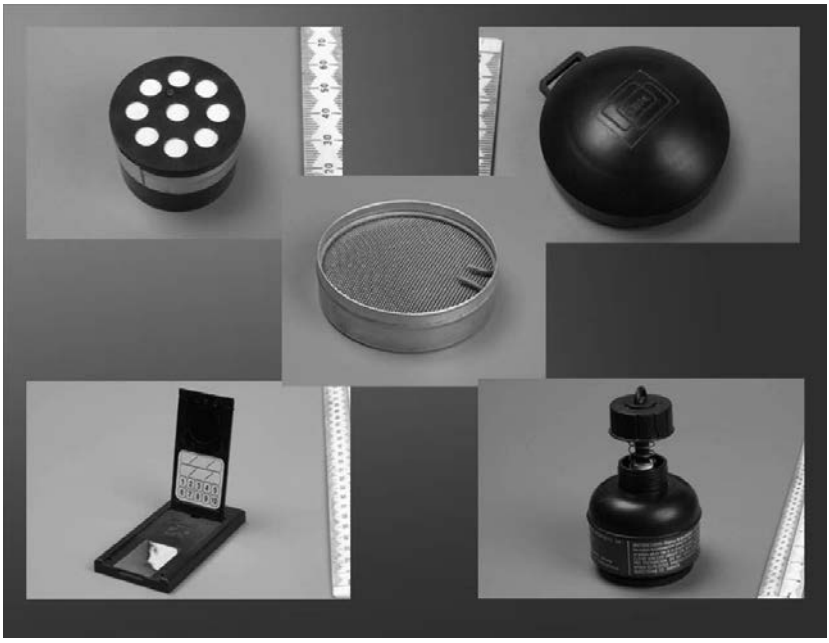
- Detector casings can absorb radon and later release it
- Allow 3 days for outgassing before packaging
- Seal in radon-proof bag
- Seal in second bag

Storage of detectors

- In case packaging is not a perfect radon barrier, store in low-radon environment
- Wooden shed (effectively outdoors)
- Alternative - Container with activated charcoal

Detector types

- Closed, filtered etched-track
- Closed, slow diffusion entry etched track
- Open LR-115 etched track
- Open CR-39 etched track
- Charcoal
- Electret



Lessons about detector types and laboratories

All detector types can produce accurate results from laboratory exposures, if produced and processed by a competent laboratory.

All detector types can produce very bad results if not processed by a competent laboratory.

All laboratories, even very good ones, make mistakes sooner or later.

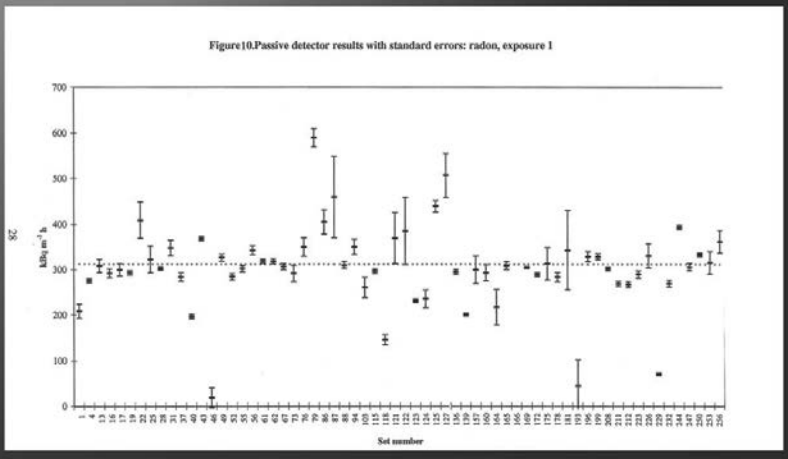
How can participants rely on results?

Traceability of radon standards to national laboratory

Documented procedures

Comparison with results from other laboratories

Graph of results can be very useful



Best accuracy by detector type

Holder	Detector material	Minimum % standard deviation
Canister	Activated charcoal	1.0
E-Perm L	Electret	2.3
NRPB/SSI	CR-39	2.7
Karlsruhe FN	Polycarbonate	4.3
NRPB	CR-39	4.6
ANPA	Cellulose nitrate	4.7

Lessons from outside the laboratory

- Open LR-115 detectors fade in sunlight
- Thoron exposures affect open detectors and closed detectors with filters
- Closed detectors with long half-time for radon entry work the same in homes as in laboratories

Closed etched-track

- Ones with filters respond to thoron as well as radon
- Ones without filters respond only to radon
- Long half-time for radon entry does not affect integration over varying concentrations

Very short exposures

FRED – Fast Radon Exposure Device

60 – 80 kBq m^{-3}

Exposure times down to 30 minutes

Charcoal detectors

Have to be returned to originating laboratory quickly, so not 'blind'

Generally accurate results for period of exposure

Only monitor short exposures

Do not correctly integrate over varying concentrations

Electret detectors

Generally accurate results

Uncertainty caused by sensitivity to gamma exposure

Dropping can cause error in estimated exposure

Trends over time

- Open detectors used much less
- Most detectors now small
- Most detectors now standard designs
- Most now made of conducting plastic
- Most now without filter

Value of intercomparisons

- Improve accuracy and traceability
- Cheap calibration and quality control
- Opportunity to try new designs
- Chance to learn from colleagues

6.2 List of participants

We need to remark in this section that some of the participants decided to send their detectors instead of attending the intercomparison meeting. These laboratories sent their sets of detectors in advance and the organizers were in charge of performing the different exposures. Table 12 shows a list of all the participants in this exercise.

Table 12: Participants in the exercise radon indoors with passive detectors

Country	Institution
Austria	Austrian Agency for Health and Food Safety
Belarus	Republic Center of Radiation Medicine and Human Ecology, Radiation Defence Laboratory
Belgium	Federal Agency for Nuclear Control
Germany	Bundesamt für Strahlenschutz
Hungary	RADOSYS Ltd
Italy	Dipartimento di Scienze Ambientali – Seconda Università di Napoli
Italy	Mi.am srl
Italy	ARPA
Norway	NRPA (Norwegian Radiation Protection Authority)
Poland	Institute of Nuclear Physics PAN
Portugal	Instituto Tecnológico e Nuclear, I.P.
Portugal	Laboratory of Natural Radioactivity, University of Coimbra
Romania	University Babes-Bolyai/Environmental Radioactivity and Nuclear Dating
Romania	IFIN-HH Bucharest
Slovenia	Institute of Occupational Safety
Spain	Grupo de Física de las Radiaciones. Departamento de Física. Universidad Autónoma de Barcelona
Spain	Universidad de Extremadura. Badajoz
Spain	Universidad de Las Palmas de Gran Canarias
Spain	University of Cantabria
Spain	University of Extremadura. Caceres
Spain	Instituto de Salud Carlos III
Spain	Medidas Ambientales
Sweden	Gammadata Mätteknik AB
Sweden	Independia Control AB
UK	HPA

6.3 Characteristics of the radon detectors used in the intercomparison

The participants were asked for the next information about the detectors used in the intercomparison: contact details of laboratory, device name as used in the laboratory, design and type of detector (Solid State Nuclear Track detector or SSNTD, electret or activated charcoal) and technical specifications of the detector. Table 13 summarizes the characteristics of the detectors used in IFC11 submitted by the participants including the laboratory code for each type of detector in order to allow identification in the following section.

Table 13: Type of radon passive detectors used at IFC11 with their characteristics and laboratory codes for further identification

Instrument type	Detector	Thickness (mm)	Total Area (mm^2)	Type and filter	Range of exposure (kBq/m^3 h)	Laboratory code
	CR39	1	100	Air gap	40 – 12000	IFC11_01
		-	-	no	40 -12000	IFC11_20
		1	100	Air gap	12000	IFC11_22
		1	46.8	no	-	IFC11_29
		1	100	no	50 – 15000	IFC11_44
	LR-115	0.01	147	Silicon rubber, membrane	(0,020-$1 \cdot 10^2$) kBq/m^3	IFC11_02
	Makrofol	0.3	100	Glass fiber	60 – 10000	IFC11_07
	LR-115	0.01	850	Polyethylene bag	100 – 5000	IFC11_11
	CR39	1.5	625	Air gap	20 – 40000	IFC11_13

	CR39	1	625	Plastic box	30 – 20000	IFC11_14
	CR39	1	361	no	-	IFC11_17
		-	-	-	10 – 25000	IFC11_25
		1.5	300	Air gap	20 – 50000	IFC11_42
		1.5	300	Air gap	10 – 25000	IFC11_42
		1	936	no	0 – 45000	IFC11_45
	Makrofol	0.49	346 (analysed area: 53)	Fibreglass GF69	24 – 1000	IFC11_26
	Activated charcoal (gamma spectrometry)	-	-	-	-	IFC11_27
		-	-	-	-	IFC11_33
		-	77 g of charcoal	no	10 – 15000 (Bq/m^3)	IFC11_37
	Electret	1.52	30	no	9000 – 100000 (Bq/m^3)	IFC11_30
		-	-	-	-	IFC11_38
No picture	CR39	-	-	no	-	IFC11_03
	CR39	1	50	Air gap	-	IFC11_09
			150		-	
			2 x 50		-	
	CR39	0.8	100	Air gap	19.7 – 12000	IFC11_18
	LR-115	0.012	1750	no	1 - 2000	IFC11_19
	CR39	1	100	Air gap	40 – 12000	IFC11_21

We can see from Table 13 that we can find five different types of detectors: CR39 (18 sets), LR-115 (3 sets), Makrofol (2 sets), activated charcoal (3 sets) electrets (2 sets) were used. Activated charcoal and electret provide the results in terms of radon concentration not radon exposure. Thus in the next section we will present the results separating radon concentrations and radon exposures.

6.4 Results and discussion

Figure 13: Detail of detectors installed in one of the rooms located in the ground floor for radon indoors passive detectors exercise

Participants were requested to submit the results in terms of radon exposures although some of them due to the characteristics of the radon detectors used gave the result in terms of radon concentrations. Participants reported their uncertainties in three different ways: k=1, k=2 and standard deviation. Exposures were done in the ground floor (2 different rooms) and first floor. Some detectors were separated from the total to be used as transits. The transit exposure was considered as exposure number 4. 15 detectors were necessary for each exposure and 15 more to be used as transits. Figure 13 shows how the passive detectors were installed in the room for the exposure.

Table 14 shows the characteristics of the radon exposures and the number of participants in each. In addition, 9 laboratories gave the results of the transits and they were used for exposure number 4, the transits exposure. Some laboratories subtracted the value of transits from the results for the exposures 1, 2 and 3. In the same Table, we can see the average results for each type of detector (with standard deviation in brackets). In the case of exposure 2, there is only 2 results for activated charcoals and 1 for the electret group. For exposures 1 and 2 the units correspond to radon concentration units (Bq m^{-3}) and exposure 3 is given in radon exposure units (kBq h m^{-3}).

Table 14: Characteristics of the radon indoors exposures. Data with asterisk indicates that the value corresponds with radon concentration not radon exposure

Exposure	1	2	3
Start	24/5/2011 (12:30)	25/5/2011 (17:30)	26/5/2011 (11:30)
End	8/6/2011 (18:30)	16/6/2011 (20:10)	13/6/2011 (11:15)
Number of participants	24	22	17
CR39	9685 (1258)	1317 (119)	103 (17)*
LR-115	5047 (6232)	1285 (53)	91 (10)*
Activated charcoal	1227 (155)	290 (85)	-
Makrofol	9101 (2585)	1205 (233)	108 (0.4)*
Electret	791 (288)	250	-

We can see from Table 14 interesting results first for exposures number 1 and 2. It is clear that there are two different groups of results. Activated charcoals and electrets gave a radon concentration much lower than the rest of the groups. The reason for this could be the exposure time. While electrets and charcoals were exposed some days, the other groups of detectors were exposed longer time. The changes in the radon concentration in the room are quite high due to natural conditions. The same applies for exposure 3. The big standard deviation in the case of LR-115, 123 % from the mean value is explained for the big difference in the radon concentration reported by the two laboratories using this type of detector. Laboratory IFC11_11 reported a value of radon exposure of 9454 kBq h m^{-3} which is in good agreement with the radon exposures reported by the rest of the participants for exposure number 1. However, participant IFC11_02 obtained a radon concentration of 640 Bq m^{-3} which represents the lowest radon concentration comparing data from all the participants. Finally in the case of the exposure number 3, we can observe a good agreement among the three groups of detectors which took part in this radon exposure.

We can start now to analyse the data obtained for radon exposures 1, 2 and 3 using CR39, LR-115 and Makrofol. The statistical analysis shows that all the data for the three exposures follow a normal distribution which will be characterized by the mean value and standard deviation (see Table 15). The ANOVA test also indicates that the values from the different laboratories can be compared. Special situation is observed in exposure number 4 or transit detectors. Achieved values do not follow a normal distribution and are quite disperse as we can check later on. In all cases the standard deviation from the mean value is less than 20 %.

Table 15: Results of exposures 1, 2 and 3 of radon indoors for group of detectors CR39, LR-115 and Makrofol

Exposure	1	2	3
Mean value (kBq·h m^{-3})	3521	693	104
Standard deviation (kBq·h m^{-3})	478	67	16
% Standard deviation	14	10	15

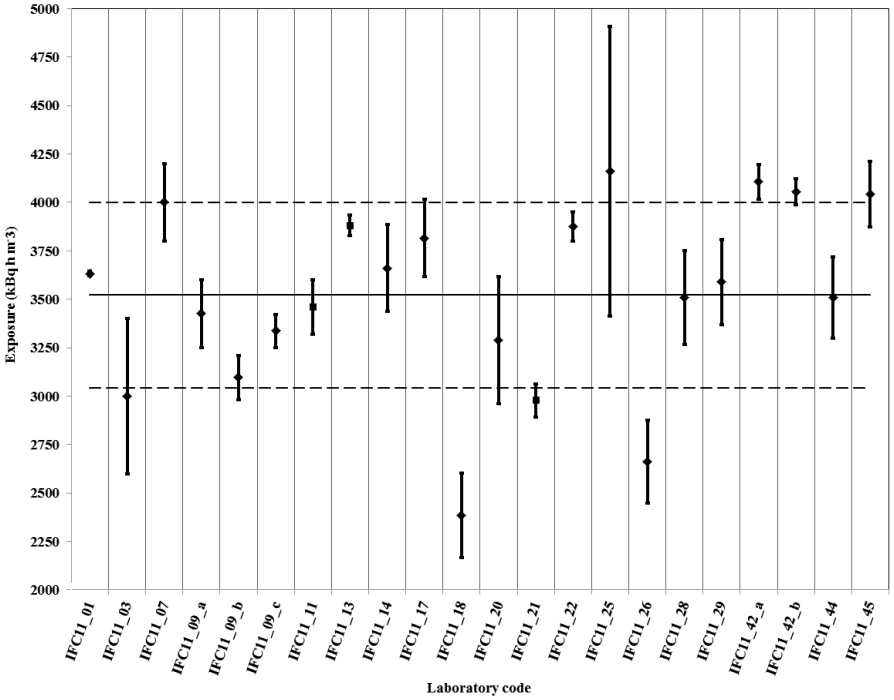


Figure 14 Graph showing the results given by participants for exposure 1. Error bars represent the uncertainty reported by each laboratory

The results for exposure 1 show that almost all the laboratories give results inside limits of standard deviation from the mean value and they are represented in Figure 14. Only two laboratories, IFC11_18 and IFC11_26 obtained results outside these limits with a radon exposure less than the average value. It is important to remark that the uncertainty of laboratories IFC11_01 and IFC11_25 are the highest of all the participants, 22% and 18% respectively. In the case of IFC11_01 this value for the uncertainty corresponds with k=2 while IFC11_25 did not specify how uncertainty was determined. Some sets of detectors achieved results similar to the mean value: IFC11_09, IFC11_13, IFC11_29 and IFC11_44.

The second radon exposure is represented in Figure 15. The results from the participants are closer than in the case of exposure 1. The standard deviation from the mean value is lower and almost all the results are inside the limits of 1 standard deviation. As well as in exposure 1, participants IFC11_18 and IFC11_26 obtained values inferior from the mean value. In general, the uncertainties of the laboratories are lower than in the case of exposure 1.

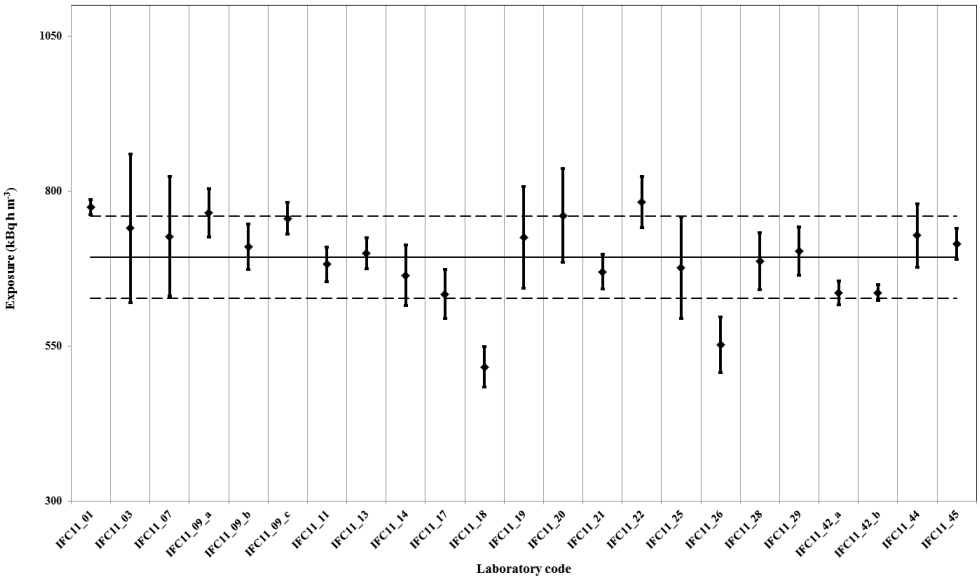


Figure 15 Results of indoor radon exposure number 2 for the group of detectors CR39, Makrofol and electrets

Finally, Figure 16 shows the results obtained for the exposure with the lowest values. This part of the exercise was done in the first floor of the building. It was also the longest exposure in time. It is always tricky to measure low values of radon exposures and this was the interest of this part of the exercise since it is difficult to perform low radon exposure intercomparisons in the routine exercises organized by reference laboratories. Only laboratories IFC11_17 and IFC11_22 gave a result outside the limits of standard deviation from the mean value. These participants reported a value higher than the rest of the laboratories. The rest have a good agreement for this low radon exposure. It is interesting to remark that three participants presented a high uncertainty of their results, IFC11_07, IFC11_17 and IFC11_29 with values of 39 %, 24% and 24% respectively. In all the cases the uncertainty was expressed as standard deviation from the reported average value.

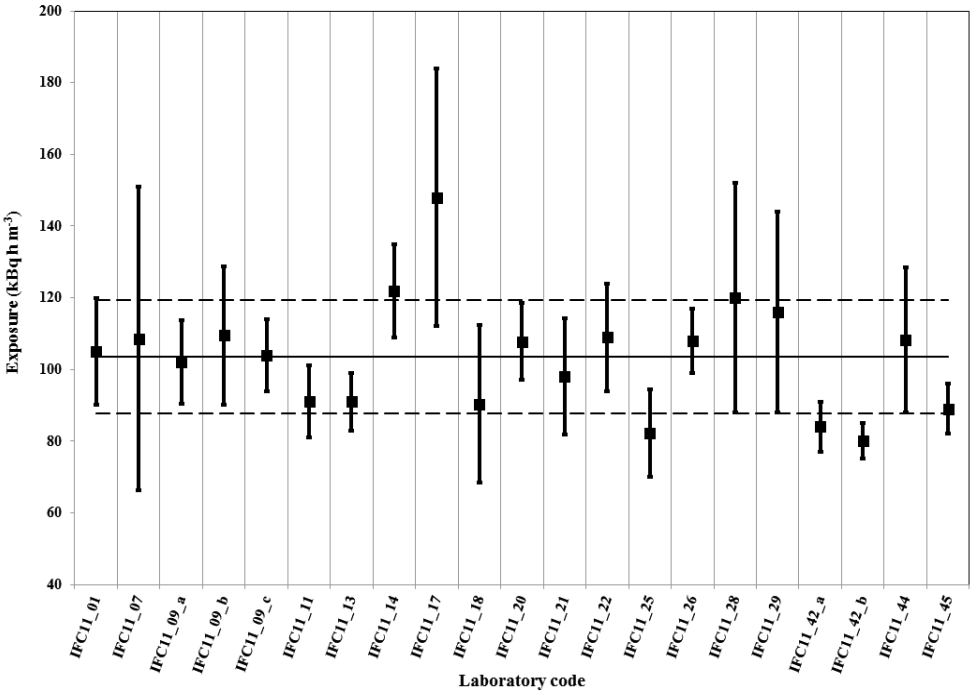


Figure 16 Exposure number 3 for detector types CR39, Makrofol and electrets. This exposure was done in the first floor of the building

As we have mentioned above, we can find in Table 16 the results corresponding to the transit detectors which can be interpreted as exposure number 4. This exposure does take into account the possible effects due to the transport of detectors to the corresponding laboratories and other conditions which can influence the values. We can use this exposure as another example of very low exposure values. The mean value obtained was 62 kBq m^{-3} with a standard deviation of 23 %. The lowest values for this exposure correspond to participants IFC11_22 and IFC11_44 with a result of 27 and 41 kBq m^{-3} respectively.

Table 16: Results for the transits exposure (exposure number 4)

Laboratory	Exp 4 (kBq h m^{-3})	Unc Exp 4 (kBq h m^{-3})
IFC11_01	70	19
IFC11_03	78	54
IFC11_07	74	41
IFC11_09_a	59	16
IFC11_09_b	55	17
IFC11_09_c	67	23

IFC11_22	27	9
IFC11_26	69	6
IFC11_29	70	19
IFC11_28	73	22
IFC11_42_a	63	
IFC11_42_b	64	
IFC11_44	41	11
IFC11_45	55	17

Table 17 shows a summary of the results provided by the participants. The table is organized in two groups of laboratories: laboratories with results in terms of Radon exposure (kBq h m^{-3}) and laboratories with results of radon concentration (Bq m^{-3}).

Table 17: Summary of results obtained in the exercise radon concentration indoors. the two groups of laboratories were exposed to the same radon concentration but some results are in terms of exposure and other in terms of radon concentration

	Exposure 1		Exposure 2		Exposure 3		Exposure 4	
Laboratory	**Result**	**% Unc**	**Result**	**% Unc**	**Result**	**% Unc**	**Result**	**% Unc**
IFC11_01	3632	0.3%	774	2%	105	14%	70	27%
IFC11_03	3000	13%	740	16%			78	69%
IFC11_09_a	3426	5%	765	5%	102	11%		
IFC11_09_b	3096	4%	710	5%	110	18%		
IFC11_09_c	3337	3%	756	3%	104	10%		
IFC11_11	3460	4%	682	4%	91	11%		
IFC11_13	3881	1%	700	4%	91	9%		
IFC11_14	3660	6%	664	7%	122	11%		
IFC11_17	3816	5%	634	6%	148	24%	76	47%
IFC11_18	2384	9%	516	6%	90	24%		
IFC11_19			725	11%				
IFC11_20	3289	10%	761	10%	108	10%		
IFC11_21	2978	3%	670	4%	98	16%		
IFC11_22	3876	2%	782	5%	109	14%	27	32%
IFC11_25	4160	18%	677	12%	82	15%		
IFC11_26	2662	8%	552	8%	108	8%	69	9%
IFC11_28	3510	7%	687	7%	120	27%	73	30%
IFC11_29	3589	6%	703	6%	116	24%	70	27%
IFC11_42_a	4106	2%	636	3%	84	8%	63	
IFC11_42_b	4055	2%	636	2%	80	6%	64	
IFC11_44	3509	6%	728	7%	108	19%	41	27%
IFC11_45	4043	4%	715	3%	89	8%	55	31%
Mean	**3521**		**693**		**104**		**62**	

SD (%)	14%		10%		15%		23%
	Rn Concentration 1		Rn Concentration 2		Rn Concentration 3		
Laboratory	Result	% Unc	Result	% Unc	Result	% Unc	
IFC11_02	640	9%					
IFC11_27	1117	8%	230	8%			
IFC11_30_a	763	5%					
IFC11_30_b	819	5%					
IFC11_33	1336	4%	350	22%	96	23%	
IFC11_37	1356		250		109		
IFC11_38	763	6%					
Mean	971		277		103		
SD (%)	30%		23%		9%		

There was no reference value and we can use the criteria of the mean value in order to rank the different laboratories. We will rank only those laboratories providing results in terms of radon exposure. To do this, laboratories with the mean absolute difference (in percentage) between their results and mean value is ≤ 10 % were ranked as category A, >10% and ≤ 15% category B, > 15% and ≤ 20 % category C, > 20% and ≤ 25 % category D and finally laboratories with the mean absolute difference (in percentage) > 25 % were ranked as category E. Table 18 shows this classification as well as some characteristics of the radon detectors.

Table 18: Results ranked by category: Exp (Type of exposure), Holder (if no specification provided blank appears), Filter (If used, type of filter; blank in case of no specification). Empty categories correspond to the laboratories which did not provide data for the corresponding exposure.

Laboratory	Exp. 1	Exp. 2	Exp. 3	Holder	Filter	Material
IFC11_01	A	B	A	Close	No	CR39
IFC11_03	B	A			No	CR39
IFC11_07	B	A	A	Close	Glass fiber	Makrofol
IFC11_09_a	A	A	A		No	CR39
IFC11_09_b	B	A	A		No	CR39
IFC11_09_c	A	A	A		No	CR39
IFC11_11	A	A	B		Polyethylene bag	LR-115
IFC11_13	A	A	B	Close	No	CR39
IFC11_14	A	A	C	Close	Plastic box	CR39
IFC11_17	A	A	E	Close	No	CR39
IFC11_18	E	D	B		No	CR39
IFC11_19		A			No	LR-115
IFC11_20	A	A	A	Close	No	CR39
IFC11_21	B	A	A		No	CR39
IFC11_22	A	B	A	Close	No	CR39
IFC11_25	C	A	D	Close	No	CR39
IFC11_26	D	C	A		Fibreglass	Makrofol
IFC11_29	A	A	B	Close	No	CR39
IFC11_42_a	C	A	C	Close	No	CR39

IFC11_42_b	B	A	D	Close	No	CR39
IFC11_44	A	A	A	Close	No	CR39
IFC11_45	B	A	B	Close	No	CR39

In all the exposures, most of the laboratories offered a result within 15 % the mean value. This shows that for the case of intermediate exposures, the majority of the participants obtained similar results within 15 % the mean value of all of them. In the case of the high radon exposure and very low radon exposures, the behaviour was a little bit worst and the participants offered a big dispersion of the results.

7 Radon indoors active detectors

7.1 List of participants

Table 19: List of participants in the exercise radon indoors with active detectors

Country	**Institution**
Belgium	Federal Agency for Nuclear Control
Czech Republic	RADON v.o.s.
Hungary	University of Pannonia
Germany	Bundesamt für Strahlenschutz
Italy	Mi.am srl
Italy	Università Federico II
Norway	NRPA (Norwegian Radiation Protection Authority)
Poland	Institute of Nuclear Physics PAN
Romania	University Babes-Bolyai/Environmental Radioactivity and Nuclear Dating
Slovenia	Jožef Stefan Institute, Department of Environmental Sciences, Radon Center
Spain	Grupo de Física de las Radiaciones. Departamento de Física. Universidad Autónoma de Barcelona
Spain	Universidad de Extremadura. Badajoz
Spain	Universidad de Santiago de Compostela
Spain	University of Cantabria
Spain	Universidad de Las Palmas de Gran Canarias
Spain	CIEMAT
Spain	Instituto de Salud Carlos III

7.2 Type of detectors used

The exercise was developed in the two radon chambers located in the ground floor of the laboratory. Every participant was allowed to install as many detectors as wished and a general view of one the radon chambers with the radon monitors can be seen in Figure 17. The total number of instruments was different depending on the brand: SARAD (31), alphaguard (12), RADIM (12), RAD7 (2) and ATMOS (2). The measurements were done exclusively during the meeting and table

summarizes the type of instrument and the laboratory code in order to make easier the readings of the following graphs.

Figure 17: Example of one of the radon chambers with the radon monitors installed inside

Table 20: Model of instrument and laboratory code for the radon indoors measurements using active detectors

Model of instrument	Laboratory
SARAD	IFC11_03
	IFC11_17
	IFC11_21
	IFC11_24
	IFC11_28
	IFC11_29
	IFC11_36
ALPHAGUARD	IFC11_03
	IFC11_07
	IFC11_10
	IFC11_18
	IFC11_21

	IFC11_24
	IFC11_26
	IFC11_27
	IFC11_29
	IFC11_36
RADIM	IFC11_03
	IFC11_04
	IFC11_21
RAD7	IFC11_26
ATMOS	IFC11_26
	IFC11_29
Not specified	IFC11_13
	IFC11_16
	IFC11_30
	IFC11_37

7.3 Results and discussion

We offer in this section the graphs with the results of the radon indoors measurements using active detectors. First, we can see the detectors depending on the type of instrument (Figures 18 to 21). Finally we will show a graph with all the participants and only one instrument per laboratory.

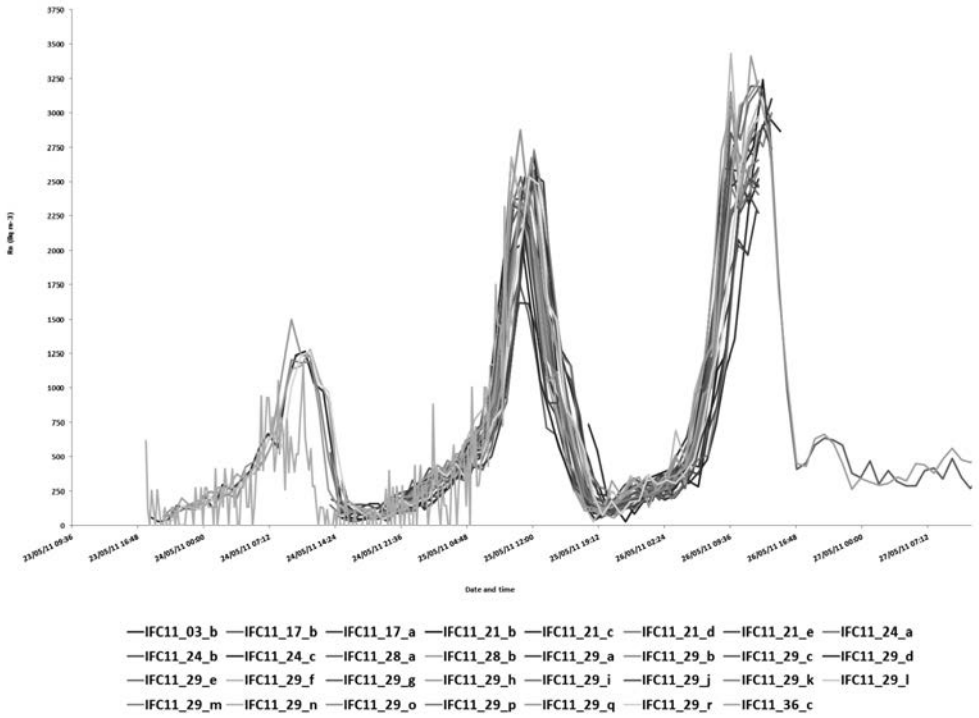


Figure 18 Results of radon indoors measurements for monitors SARAD

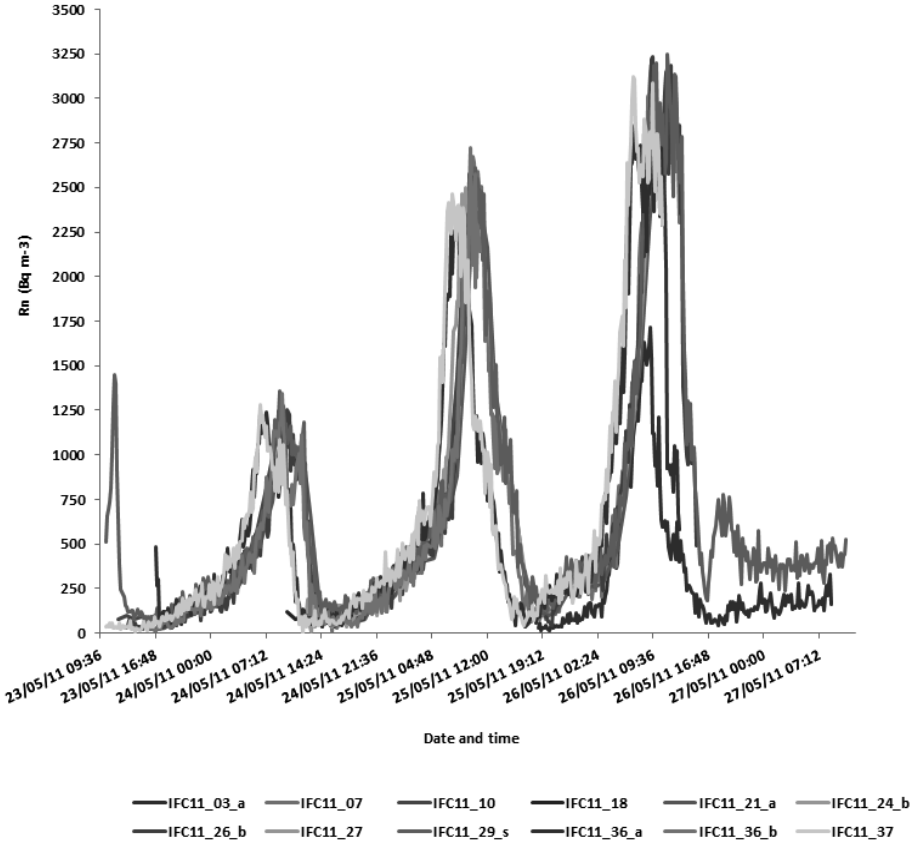


Figure 19 Results of radon indoors measurements for monitors ALPHAGUARD

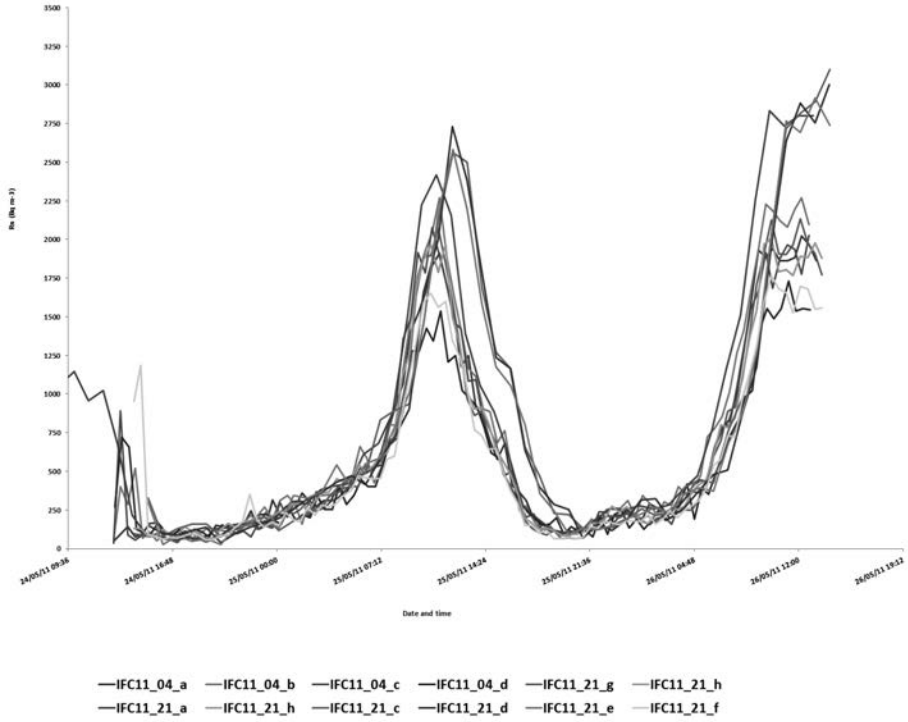


Figure 20 Results of radon indoors measurements for monitors RADIM

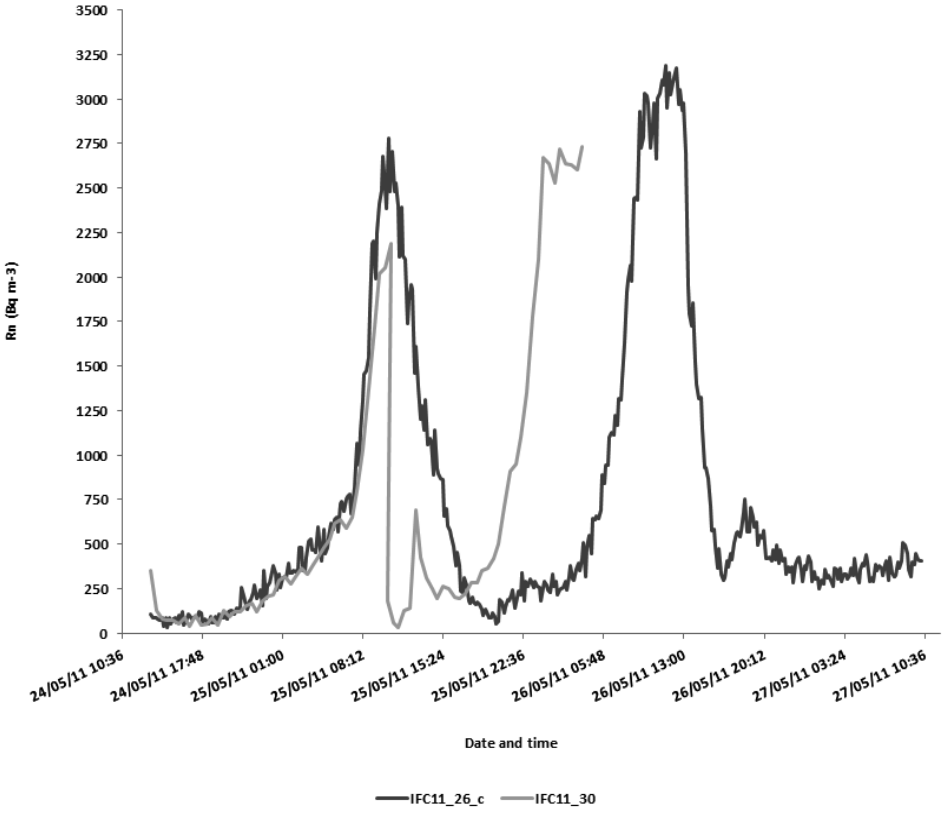


Figure 21 Results of radon indoors measurements for monitors RAD7

Now, we can see in Figure 22 a graph with results from all participants represented each one by one device.

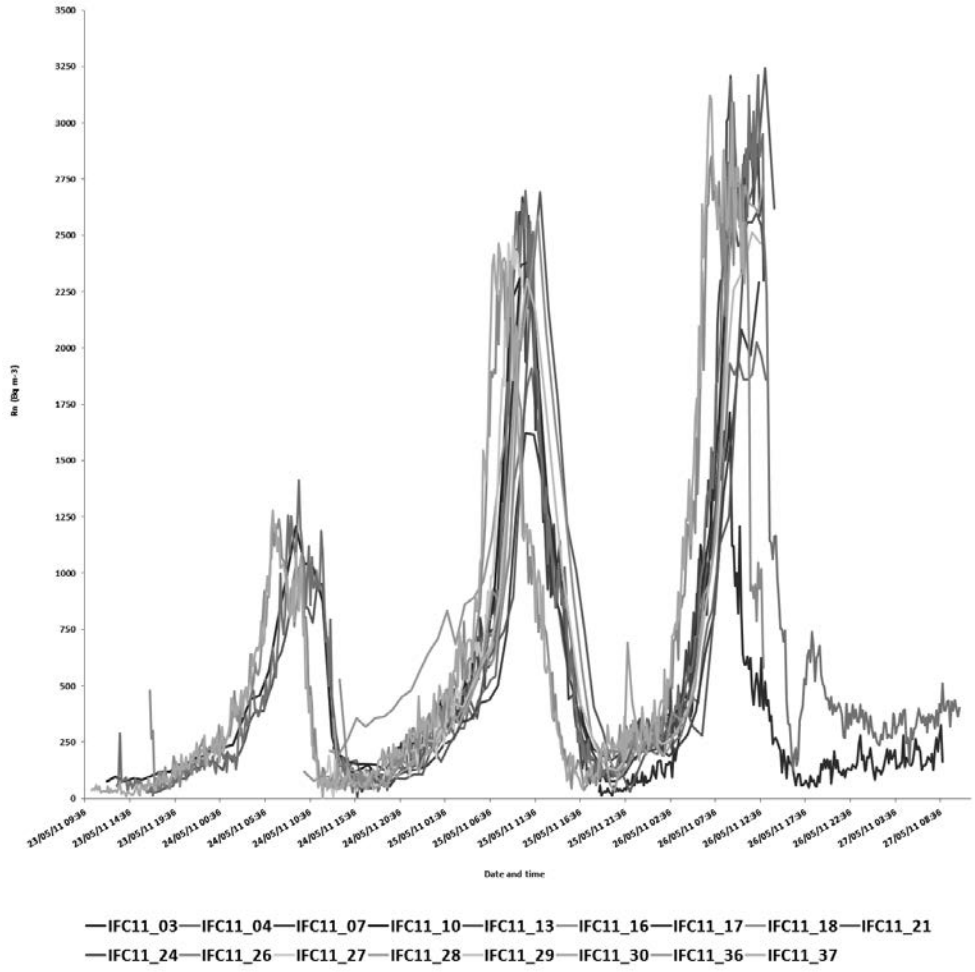


Figure 22: Results of radon indoors measurements using active detectors with all participants

We can observe in Figure 22 that the agreement among different devices is quite good. It is also possible to recognize three different areas where the maximum concentrations are reached.

Appendix I: List of participants

INSTITUTION	COUNTRY	E-MAIL
ARPA	ITALY	d.lunesu@arpalombardia.it; r.rusconi@arpalombardia.it
ARPACAL	ITALY	s.procopio@arpacal.it
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BENC BUREAU D ETUDES NUCLEAIRES, CORSE	FRANCE	radon@radon-corse.com
BUNDESAMT FÜR STRAHLENSCHUTZ	GERMANY	EFoerster@bfs.de; pbossew@bfs.de
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FEDERAL AGENCY FOR NUCLEAR CONTROL	BELGIUM	Andre.Poffijn@UGent.be; Boris.dehandschutter@fanc.fgov.be
GAMMADATA INSTRUMENTS	SWEDEN	Dag.Sedin@gammadatainstrument.se
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INSTITUTO DE SALUD CARLOS III	SPAIN	jcastro@isciii.es
INSTITUTO TECNOLÓGICO E NUCLEAR, I.P.	PORTUGAL	madruga@itn.pt
JOŽEF STEFAN INSTITUTE, DEPARTMENT OF ENVIRONMENTAL SCIENCES, RADON CENTER	SLOVENIA	janja.vaupotic@ijs.si

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NRPA (NORWEGIAN RADIATION PROTECTION AUTHORITY)	NORWAY	trine.kolstad@nrpa.no
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UNIVERSITY OF EXTREMADURA. CACERES	SPAIN	ymiralle@unex.es; fguillen@unex.es
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Appendix II: Detailed analysis of exercise "soil-gas radon concentration"

Introduction

This appendix describes results of the international intercomparison measurement of soil-gas radon concentration, which was held in Saelices el Chico (Salamanca, Spain) in May 25, 2011, as a part of the International Intercomparison Exercise on Natural Radiation Measurement under Field Conditions. The meeting was organized by University of Cantabria, Spain. This further analysis of the exercise was carried out by Martin Neznal and Matéj Neznal (Radon vos).

The soil-gas radon (222Rn) concentration **c** (kBq m^{-3}) is defined as an average radon concentration in the air-filled part of soil-pores in a given volume of soil-gas. The parameter is used for characterizing the radon potential of soils, but a large range of other applications is known: uranium prospecting, earthquake prediction, risk assessment of waste materials, etc.

Conclusions resulting from several previous intercomparison measurements are available: Badgastein, Austria, 1991 (Cliff et al. 1994), New York, U.S.A., 1995 (Hutter and Knutson 1996, 1998), Praha, Czech Republic, 1996 (Neznal et al. 1996, 1997), Czech Republic, 2002 (Neznal and Neznal, 2004b), Czech Republic, 2010.

The most important conclusions can be summarised as follows:

- From metrological point of view, there are many serious problems connected with organizing any field intercomparison measurement of soil-gas radon concentration. The natural geological environment is almost never homogeneous. The soil-gas radon concentration may vary, often very greatly, over a small distance; the variations of soil-gas radon with depth are different under changing geological conditions. Field intercomparison measurements thus are not intended to be used as an intercalibration of methods and instruments. They are designed as an intercomparison of results obtained using different instruments and methods employed in the field in order to assess the ability to interrelate diverse measurements. Under these circumstances, values are not reported against a standard or reference measurement. Participant's results are simply compared to each other, in order to obtain an indication of the collective precision of various measurements.

- 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. If these requirements are not fulfilled, a large variability of measurement results can be expected.

Participants and methods

The intercomparison measurement of soil-gas radon concentration was attended by participants representing 18 different institutions, marked by following codes: IFC11_03, IFC11_04, IFC11_06, IFC11_10, IFC11_11, IFC11_13, IFC11_16, IFC11_17, IFC11_18, IFC11_20, IFC11_21, IFC11_24, IFC11_26, IFC11_27, IFC11_29, IFC11_30, IFC11_40, IFC11_43. The evaluation of results was anonymous, based on measurement protocols. A sample protocol was prepared by the organizers, filled-in by all participants and sent for the evaluation. Unfortunately, the quality of

several protocols was very poor. Many important data and information are thus missing.

Spectrum of techniques, that were tested during the intercomparison exercise, was large. The volume of collected soil-gas samples was also very variable. Basic information on sampling and measuring methods, as well as on the quality of protocols, is given in Table 1 and Table 2.

Table 1 Sampling methods – summary

Participant	Sampling system	Sampling depth (cm)	Time of sampling *)	Volume of soil-gas samples (l)
IFC11_03	Neznal probe (diameter 0,8 - 1,2 cm); syringe	50 - 63	reported	0,15
IFC11_04	Neznal probe; syringe	55 - 60	reported	0,1
IFC11_06	?	?	?	?
IFC11_10	probe (diameter 0,8 - 1,2 cm); AlphaGuard pump: 1 l/m	50 - 55	reported	0,56
IFC11_11	Neznal probe, pump: 1 l/m	45 - 80	reported	30
IFC11_13	probe GND100 (diameter 1 - 1,4 cm); MR1 pump: approx. 0,25 l/m	40 - 60	reported	3
IFC11_16	Neznal probe, pump: 1 l/m	45 - 80	reported	30
IFC11_17	?	50	?	?
IFC11_18	AlphaGuard probe; AlphaGuard pump: 0,5 l/m	40 - 60	?	10
IFC11_20	dual probe (circulation), inserted in a 2 cm drilled hole; pump: 1 l/m	65	?	14 - 61
IFC11_21	?	50 - 80	?	?
IFC11_24	Neznal probe; pump 1 l/m	80	reported	0,31
IFC11_26	STITZ probe (exterior probe diameter 1,2 - 2,2 cm; interior probe diameter 0,2 - 0,6 cm); AlphaGuard pump: 1 l/m	45 - 60	reported	1
IFC11_27	AlphaGuard sonda a AlphaGuard pumpa 1 l/m	50	?	15
IFC11_29	Neznal probe; syringe	60	reported	0,1
IFC11_30	?	50 - 70	reported	?
IFC11_40	?	?	reported	?
IFC11_43	?	50	?	?

Note: *) A misunderstanding occurred: Some participants have reported a duration of sampling as the time of sampling (instead of the time when the sample collection started).

Table 2 Measuring methods – summary

Participant	Method	Instrumentation	Calibration of the instrument	Elimination of thoron influence
IFC11_03	scintillation	LUK 3A	reported	yes
IFC11_04	ionization	LUK 4A	reported	yes
IFC11_06	?		?	?
IFC11_10	ionization	AlphaGuard	reported	no
IFC11_11	silicon detector	Ramona 2.0	reported	?
IFC11_13	scintillation	MR1	reported	?
IFC11_16	silicon detector	Ramona 2.0	reported	?
IFC11_17	?	Markus 10	reported	?
IFC11_18	ionization	AlphaGuard PQ 2000 PRO	reported	yes
IFC11_20	ionization	AlphaGuard Pro	reported	?
IFC11_21	scintillation	LUK 3C	reported	?

IFC11_24	scintillation	PRM-145	reported	yes
IFC11_26	ionization	AlphaGuard	reported	yes
IFC11_27	ionization	AlphaGuard PQ 2000 PRO	reported	yes
IFC11_29	scintillation	LUK 4A	?	yes
IFC11_30	?	?	?	?
IFC11_40	ionization	RM-2 (SARAD RTM 2100)	?	?
IFC11_43	?	MARKUS 10	?	?

Test site

The intercomparison exercise of soil-gas radon concentration was organized at a test site near the parking in the compound of former uranium mine facility in Saelices el Chico. There is a grove (meadow and several trees) on the surface.

Eight basic reference points (A, B, C, D, E, F, G, H) were marked at the test site - See Figure 1. The participants were asked to take samples primarily in the surroundings of the eight reference points.

The coordinates of the test site, reported by participant IFC_18, were following:

A N40 37.877 W6 36.009,

B N40 37.881 W6 36.001,

C N40 37.890 W6 35.999,

D N40 37.895 W6 35.992,

E N40 37.892 W6 35.984,

F N40 37.884 W6 35.988,

G N40 37.879 W6 35.993,

H N40 37.872 W6 36.002.

Some participants realized measurements also in the surroundings of other points at the test site: point AH located approx. in the middle between reference points A and H; point BG located approx. in the middle between reference points B and G; point CF located approx. in the middle between reference points C and F; point DE located approx. in the middle between reference points D and E; point FG located approx. in the middle between reference points F and G.

Due to the conditions at the test site, a uniform sampling depth of 60 cm below the ground surface was recommended for soil-gas radon concentration measurements.

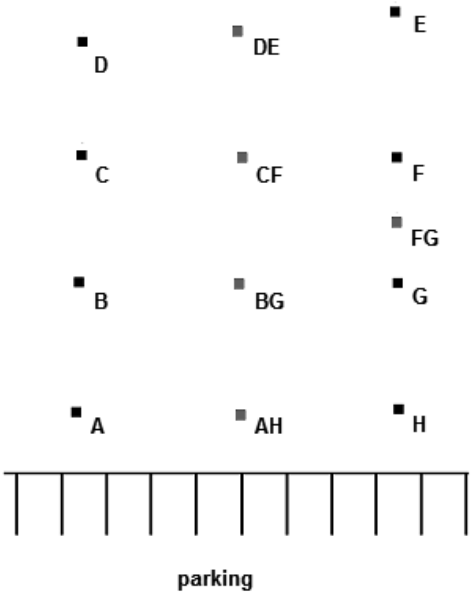

Figure 1 Reference points (A - H) marked at the test site

Results

Results of all soil-gas radon concentration measurements, including information on the locations of measuring points, on the depth of sample collection, on the sampling time, and on the volume of soil-gas sample (if available) are given in Table 3.

Table 3Results of soil-gas radon concentration measurements

Participant	Point	Depth (cm)	Time	Volume (l)	cRn (kBq m^{-3})	Uncertainty (kBq m^{-3})	Note
IFC11_03	A	55	13:36	0,15	9,7	0,5	
	B	65	13:52	0,15	46	2	
	C	58	13:15	0,15	44	2	
	D	55	12:59	0,15	24	1	
	E	50	12:45	0,15	104	4	
	F	60	12:31	0,15	32	1,5	
	G	60	12:17	0,15	111	4	
	H	55	11:35	0,15	17	0,8	
	AH	52	15:23	0,15	21	1	
	BG	63	15:40	0,15	15	0,7	
	CF	62	15:55	0,15	102	4	
	DE	55	16:10	0,15	11	0,6	
IFC11_04	A	60	13:15	0,097	10,7	0,3	
	B	60	12:51	0,1	46,6	0,7	
	C	60	12:48	0,1	77,4	0,9	

	D	60	12:31	0,1	32,5	0,5	
	E	60	12:08	0,1	57,3	0,7	
	F	60	12:01	0,1	39,2	0,6	
	G	60	11:58	0,1	241	1,6	
	H	60	11:54	0,1	19	0,4	
	AH	60	13:57	0,1	15,7	0,3	
	BG	60	14:00	0,1	4,1	0,1	
	CF	55	14:09	0,1	81,1	0,9	
	DE	60	15:26	0,1	18	0,4	
	A	*60*	*13:19*	*0,1*	*10,6*	*0,3*	*another point in the surroundings of A*
	DE	*60*	*17:00*	*0,1*	*18,3*	*0,4*	*repeated sampling from the same probe*
IFC11_06	FG				170	8,5	
IFC11_10	B	50	12:00	0,56	97,4	19,4	
	C	50	12:25	0,56	118,4	30,2	
	E	50	14:40	0,56	96,1	18,3	
	F	50	14:00	0,56	57,3	12,6	
	G	55	12:55	0,56	213,3	36,5	
	H	50	13:30	0,56	325	9,6	
IFC11_11	B	60	15:35	30	35	2	
	C	60	14:36	30	34	3	
	D	45	14:04	30	21	2	
	E	45	13:22	30	60	7	
	F	80	12:00	30	22	2	
	G	60	12:47	30	64	6	
	H	60	16:35	30	21	3	
IFC11_13	B	60	13:30	3	29,2		
	C	40	12:15	3	14,3		
	E	40	16:10	3	8,6		
	F	60	13:00	3	15,0		
	G	50	11:45	3	44,4		
	H	40	14:00	3	19,5		
IFC11_16	B	60	15:35	30	35	4	
	C	60	14:36	30	33	4	
	D	45	14:04	30	22	3	
	E	45	13:22	30	57	6	
	F	80	12:00	30	23	3	
	G	60	12:47	30	65	7	
	H	60	16:35	30	21	3	
IFC11_17	E	50			66	3	
	G	50			176	9	
	H	50			29	1	
IFC11_18	A	50		10	60,3	2,3	
	B	60		10	27,6	3,5	
	C	60		10	18,8	3,1	
	D	40		10	51,3	2,1	
	E	50		10	37,3	2,6	
	F	60		10	10,9	3,2	

	G	60		10	88,8	3,4	
	H	60		10	35,8	3,4	
IFC11_20	A	65		26	0,50	0,02	
	B	65		31	13,63	0,68	
	C	65		61	68,30	3,42	
	D	65		20	24,32	1,22	
	E	65		26	80,28	4,01	
	F	65		18	19,23	0,96	
	G	65		15	42,91	2,15	
	H	65		14	30,44	1,52	
IFC11_21	A	60			8,10	1,00	
	B	50			29,16	2,16	
	C	65			33,60	2,09	
	D	65			17,23	1,17	
	E	50			45,43	3,79	
	F	50			35,03	2,45	
	G	60			120,87	8,14	
	H	50			13,17	0,97	
	E	*80*			*47,90*	*4,20*	*another sampling depth*
IFC11_24	A	80	16:57	0,31	4,4	0,2	
	B	80	12:45	0,31	39,9	0,6	
	C	80	15:10	0,31	65,0	1,1	
	D	80	14:07	0,31	18,8	0,3	
	E	80	15:28	0,31	39,8	0,5	
	F	80	13:27	0,31	16,5	0,8	
	G	80	12:19	0,31	320	3	
	H	80	13:15	0,31	15,1	0,4	
	F	*80*	*12:25*	*0,31*	*35,2*	*0,7*	*repeated sampling the next day (26.5.2011)*
	G	*80*	*12:10*	*0,31*	*286*	*3*	*repeated sampling the next day (26.5.2011)*

IFC11_26	B	60	13:30	1	22,5	1,4	
	C	60	12:50	1	66,7	3,2	
	D	45	11:45	1	18,8	1,0	
	G	60	16:30	1	201,7	7,7	
	H	60	15:30	1	12,4	0,7	
	H	*60*	*16:10*	*1*	*15,7*	*0,8*	*repeated m. (another hole)*
IFC11_27	C	50		15	48	3	
	E	50		15	123	5	
	H	50		15	33	4	
IFC11_29	A	60	13:20	0,1	11,8	0,2	
	B	60	13:15	0,1	51,1	0,5	
	C	60	13:00	0,1	69,7	0,7	
	D	60	12:48	0,1	35,8	0,7	
	E	60	12:33	0,1	63,2	0,6	
	F	60	12:25	0,1	35,3	0,7	
	G	60	12:00	0,1	264,0	2,6	
	H	60	11:40	0,1	17,0	0,3	
IFC11_30	E	50			77,2	3,6	4 different values for each point were reported; average values are presented here
	F	70			13,7	1,4	
	G	50			29,9	2,1	
	FG	50			162,3	5,2	
	F	*50*			*22,5*	*1,9*	*repeated m. - other depth*
	FG	*60*			*166*	*5,3*	*repeated m. - other probe and depth*
IFC11_40	A		13:51		5,1		RM-2
	B		13:10		48,1		RM-2
	C		12:51		35,7		RM-2
	D		11:57		18,5		RM-2
	E		12:22		83,2		RM-2
	F		16:43		26,8		RM-2
	G		15:53		26		RM-2
	H		13:55		19,4		RM-2
	A		*15:29*		*0,5*		*repeated meas. (RM-2)*
	H		*15:29*		*15,1*		*repeated meas. (RM-2)*
	G		*16:05*		*24,9*		*repeated meas. (RM-2)*
	B		*13:52*		*35,6*		*repeated measurement (SARAD RTM 2100)*

	C		*13:13*		*32,7*		*repeated measurement (SARAD RTM 2100)*
	D		*11:55*		*17,8*		*repeated measurement (SARAD RTM 2100)*
	E		*12:33*		*78,7*		*repeated measurement (SARAD RTM 2100)*
	F		*16:52*		*20,2*		*repeated measurement (SARAD RTM 2100)*
	G		*16:19*		*32,9*		*repeated measurement (SARAD RTM 2100)*
	H		*15:44*		*21,1*		*repeated measurement (SARAD RTM 2100)*
IFC11_43	A	50			25		
	C	50			13		
	D	50			72		
	E	50			170		
	H	50			37		

Not all data presented in Table 3 were used for the intercomparison. Results of repeated measurements (italic type) were excluded from the evaluation. Evaluated data are summarized in Table 4.

Table 4 Data used for the intercomparison – summary

Participant	Number of measurements	Points (first measurement only)
IFC11_03	12	A, B, C, D, E, F, G, H, AH, BG, CF, DE
IFC11_04	12	A, B, C, D, E, F, G, H, AH, BG, CF, DE
IFC11_06	1	FG
IFC11_10	6	B, C, E, F, G, H
IFC11_11	7	B, C, D, E, F, G, H
IFC11_13	6	B, C, E, F, G, H
IFC11_16	7	B, C, D, E, F, G, H
IFC11_17	3	E, G, H
IFC11_18	8	A, B, C, D, E, F, G, H
IFC11_20	8	A, B, C, D, E, F, G, H
IFC11_21	8	A, B, C, D, E, F, G, H
IFC11_24	8	A, B, C, D, E, F, G, H
IFC11_26	5	B, C, D, G, H
IFC11_27	3	C, D, H
IFC11_29	8	A, B, C, D, E, F, G, H
IFC11_30	4	E, F, G, FG
IFC11_40	8	A, B, C, D, E, F, G, H
IFC11_43	5	A, C, D, E, H

The intercomparison of all participating laboratories is given in Table 5 and in Figure 2.

Table 5 Intercomparison of soil-gas radon concentration data reported by different participants

Participant	Minimum (kBq m^{-3})	Maximum (kBq m^{-3})	Median (kBq m^{-3})	Ar. mean (kBq m^{-3})	SD (kBq m^{-3})	SD / mean	Number of meas.
IFC11_03	9,7	111,0	**28,0**	44,7	38,6	0,86	12
IFC11_04	4,1	241,0	**35,9**	53,6	64,2	1,20	12
IFC11_06	170,0	170,0	**170,0**	170,0			1
IFC11_10	32,5	213,3	**96,8**	102,5	62,5	0,61	6
IFC11_11	21,0	64,0	**34,0**	36,7	18,3	0,50	7
IFC11_13	8,6	44,4	**17,3**	21,8	13,0	0,60	6
IFC11_16	21,0	65,0	**33,0**	36,6	17,7	0,48	7
IFC11_17	29,0	176,0	**66,0**	90,3	76,5	0,85	3
IFC11_18	10,9	88,8	**36,6**	41,4	25,0	0,61	8
IFC11_20	0,5	80,3	**27,4**	35,0	27,4	0,78	8
IFC11_21	8,1	120,9	**31,4**	37,8	35,8	0,95	8
IFC11_24	4,4	320,3	**29,3**	65,0	104,9	1,62	8
IFC11_26	12,4	201,7	**22,5**	64,4	79,7	1,24	5
IFC11_27	33,0	123,0	**48,0**	68,0	48,2	0,71	3
IFC11_29	11,8	264,0	**43,5**	68,5	81,6	1,19	8
IFC11_30	13,7	162,3	**53,6**	70,8	66,7	0,94	4
IFC11_40	5,1	83,2	**26,4**	32,9	24,0	0,73	8
IFC11_43	13,0	170,0	**37,0**	63,4	63,5	1,00	5

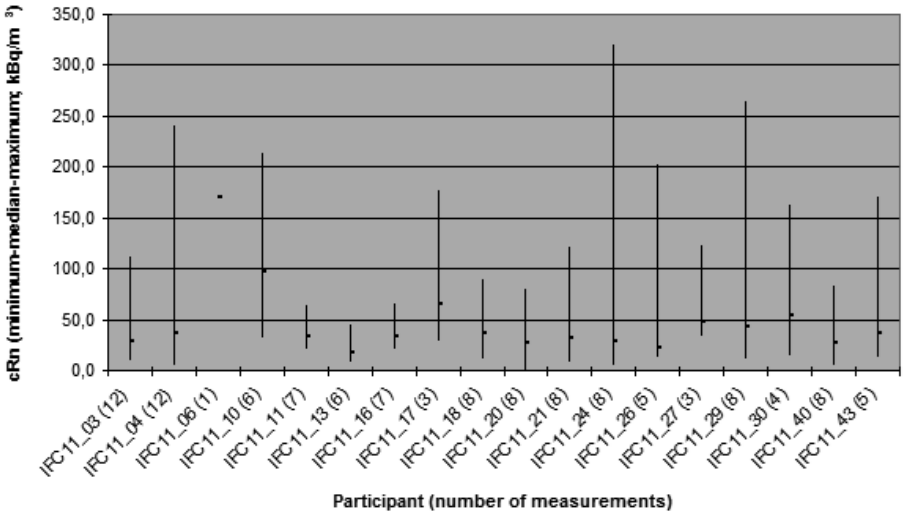

Figure 2 Intercomparison of soil-gas radon concentration data reported by different participants

Discussion

As can be seen in Table 5, median values reported by different participants ranged from 17,3 to 170,0 kBq m^{-3} (median of reported median values was equal to 34,9 kBq m^{-3}). In our opinion, the variability of results was caused by a combination of following reasons:

- A large spatial variability of soil-gas radon concentrations was observed over the test site. The

variability indicates inhomogeneous geological conditions. Local anomalies with substantially higher soil-gas radon concentrations were found. The frequency distribution of data is not normal.

- The number of measurements performed by different participants ranged from 1 to 12 measuring points. If there are some anomalies over the test site, a low number of measurements is not sufficiently representative - the results do not cover the whole area.

- Intercomparison participants used different sampling methods, volume of collected soil-gas samples ranged from 0,1 to more than 30 l.

- Varying depths of sampling may also increase the variability of data.

- In case of some participants, the method used does not allow to eliminate an influence of thoron.

- In case of some participants, no information of primary calibration of instruments is available.

Some of influencing factors will be discussed in more details.

Distribution of data

The distribution of all evaluated data is presented in Figure 3. It is evident that the distribution is not normal. A log-normal distribution would probably fit better the experimental data, but we are almost sure, that the real distribution of data is heterogeneous - observed frequency distribution is in fact a composition of two or more different distributions corresponding to different parts of the test site (See chapter Spatial variability). Gaussian parameters, such as arithmetic mean and standard deviation (SD), are thus useless. For the above mentioned reasons, we use the median value as the main statistical parameter to compare the results of different participants.

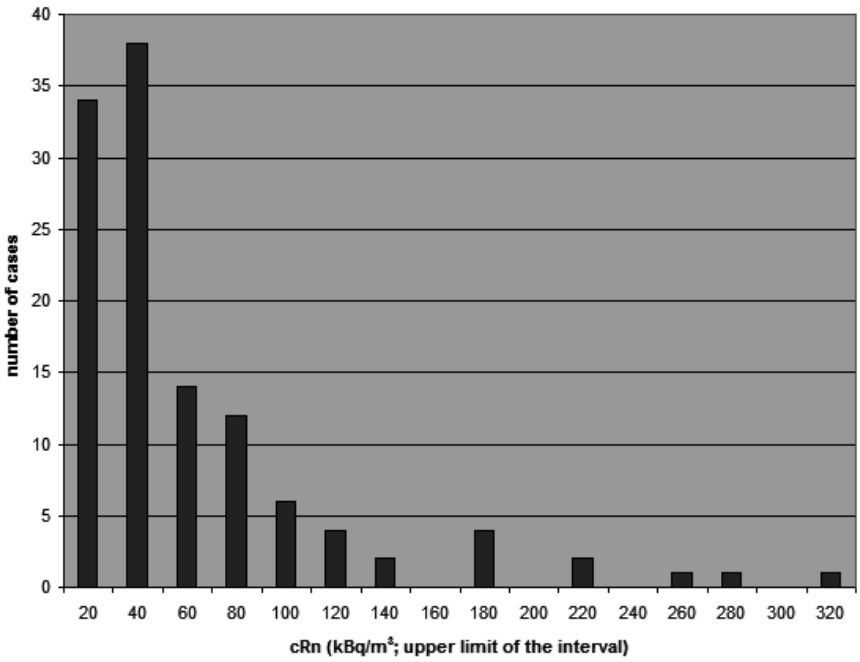

Figure 3 Distribution of data (all data evaluated)

Spatial variability

Figure 4 shows soil-gas radon concentrations measured by all participants in the surroundings of different measuring points. Median values corresponding to points E, G, CF, FG were substantially higher than median valued in the rest of the test site.

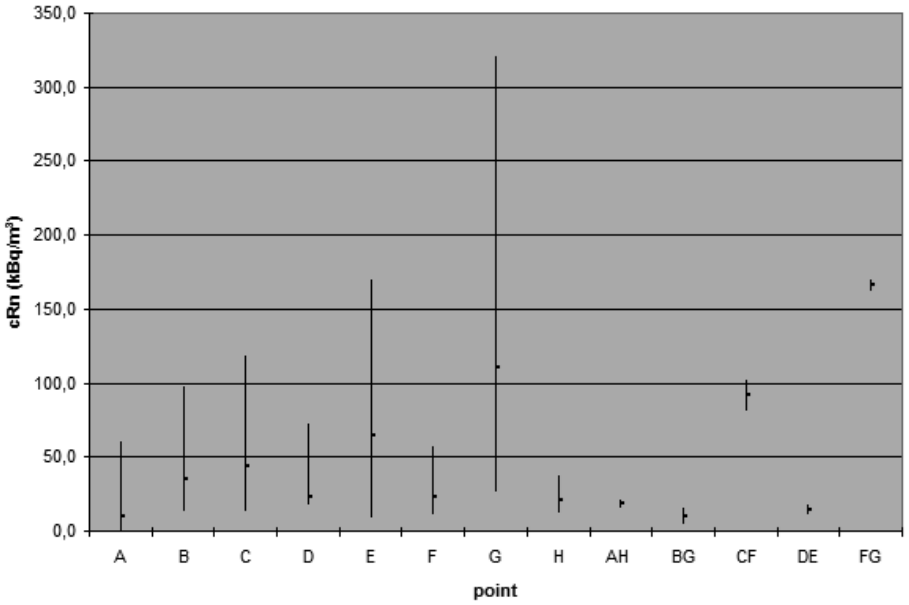

Figure 4 Soil-gas radon concentrations measured by all participants in the surroundings of different measuring points

If we divide the test site into two subareas (surroundings of points A, B, C, D, F, H, AH, BG, DE; surroundings of points E, G, CF, FG), we obtain two different distributions of data - see Figure 5 and 6. Comparison of data reported by different participants in two subareas are shown in Table 6 and 7 (see also Figure 7 and 8).

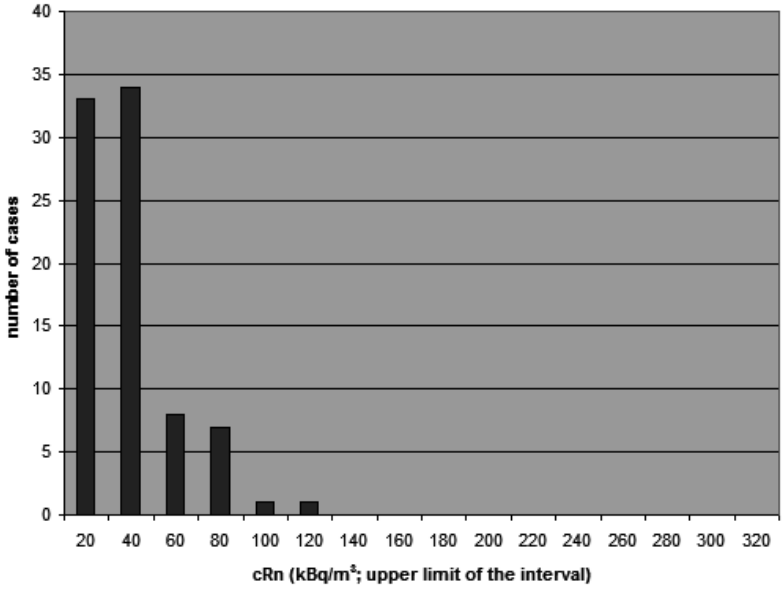

Figure 5 Distribution of data (points A, B, C, D, F, H, AH, BG, DE).

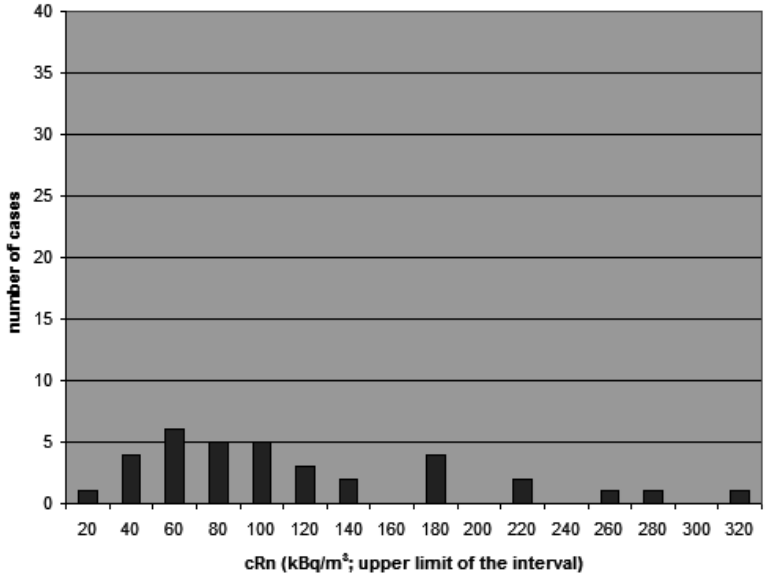

Figure 6 Distribution of data (points E, G, CF, FG).

Table 6 Intercomparison of soil-gas radon concentration data reported by different participants - surroundings of points A, B, C, D, F, H, AH, BG, DE

Participant	Minimum (kBq m^{-3})	Maximum (kBq m^{-3})	Median (kBq m^{-3})	Ar. mean (kBq m^{-3})	SD (kBq m^{-3})	SD / mean	Number of meas.
IFC11_03	9,7	46,0	**21,0**	24,4	13,5	0,55	9
IFC11_04	4,1	77,4	**19,0**	29,2	22,7	0,78	9
IFC11_06							
IFC11_10	32,5	118,4	**77,4**	76,4	38,7	0,51	4
IFC11_11	21,0	35,0	**22,0**	26,6	7,2	0,27	5
IFC11_13	14,3	29,2	**17,3**	19,5	6,8	0,35	4
IFC11_16	21,0	35,0	**23,0**	26,8	6,6	0,25	5
IFC11_17	29,0	29,0	**29,0**	29,0			1
IFC11_18	10,9	60,3	**31,7**	34,1	19,0	0,56	6
IFC11_20	0,5	68,3	**21,8**	26,1	23,1	0,88	6
IFC11_21	8,1	35,0	**23,2**	22,7	11,4	0,50	6
IFC11_24	4,4	65,0	**17,7**	26,6	22,1	0,83	6
IFC11_26	12,4	66,7	**20,7**	30,1	24,8	0,82	4
IFC11_27	33,0	48,0	**40,5**	40,5	10,6	0,26	2
IFC11_29	11,8	69,7	**35,6**	36,8	21,5	0,58	6
IFC11_30	13,7	13,7	**13,7**	13,7			1
IFC11_40	5,1	48,1	**23,1**	25,6	15,0	0,58	6
IFC11_43	13,0	72,0	**31,0**	36,8	25,5	0,69	4

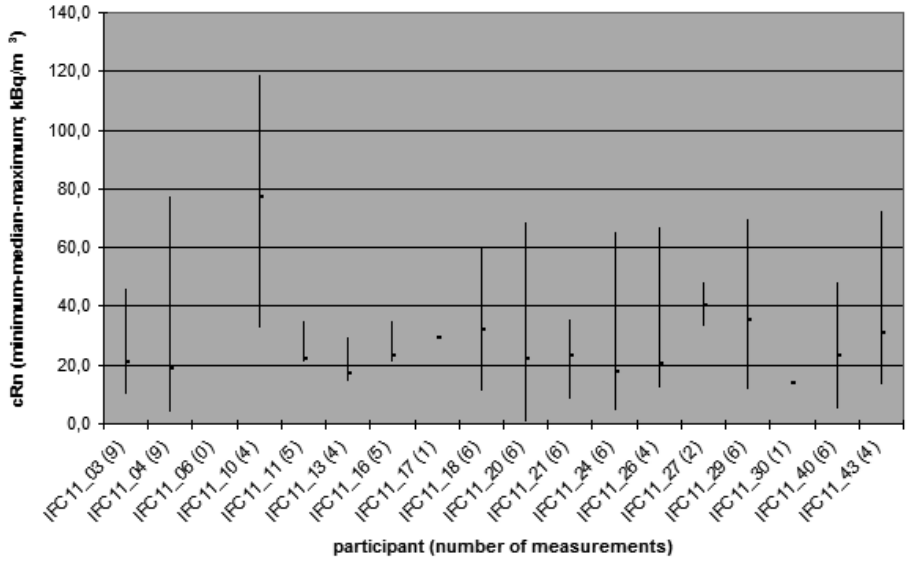

Figure 7 Intercomparison of soil-gas radon concentration data reported by different participants

Table 7 Intercomparison of soil-gas radon concentration data reported by different participants - surroundings of points E, G, CF, FG

Participant	Minimum (kBq m^{-3})	Maximum (kBq m^{-3})	Median (kBq m^{-3})	Ar. mean (kBq m^{-3})	SD (kBq m^{-3})	SD / mean	Number of meas.
IFC11_03	102,0	111,0	**104,0**	105,7	4,7	0,04	3
IFC11_04	57,3	241,0	**81,1**	126,5	99,9	0,79	3
IFC11_06	170,0	170,0	**170,0**	170,0			1
IFC11_10	96,1	213,3	**154,7**	154,7	82,9	0,54	2
IFC11_11	60,0	64,0	**62,0**	62,0	2,8	0,05	2
IFC11_13	8,6	44,4	**26,5**	26,5	25,3	0,96	2
IFC11_16	57,0	65,0	**61,0**	61,0	5,7	0,09	2
IFC11_17	66,0	176,0	**121,0**	121,0	77,8	0,64	2
IFC11_18	37,3	88,8	**63,1**	63,1	36,4	0,58	2
IFC11_20	42,9	80,3	**61,6**	61,6	26,4	0,43	2
IFC11_21	45,4	120,9	**83,1**	83,1	53,3	0,64	2
IFC11_24	39,8	320,3	**180,1**	180,1	198,3	1,10	2
IFC11_26	201,7	201,7	**201,7**	201,7			1
IFC11_27	123,0	123,0	**123,0**	123,0			1
IFC11_29	63,2	264,0	**163,6**	163,6	142,0	0,87	2
IFC11_30	29,9	162,3	**77,2**	89,8	67,1	0,75	3
IFC11_40	26,0	83,2	**54,6**	54,6	40,4	0,74	2
IFC11_43	170,0	170,0	**170,0**	170,0			1

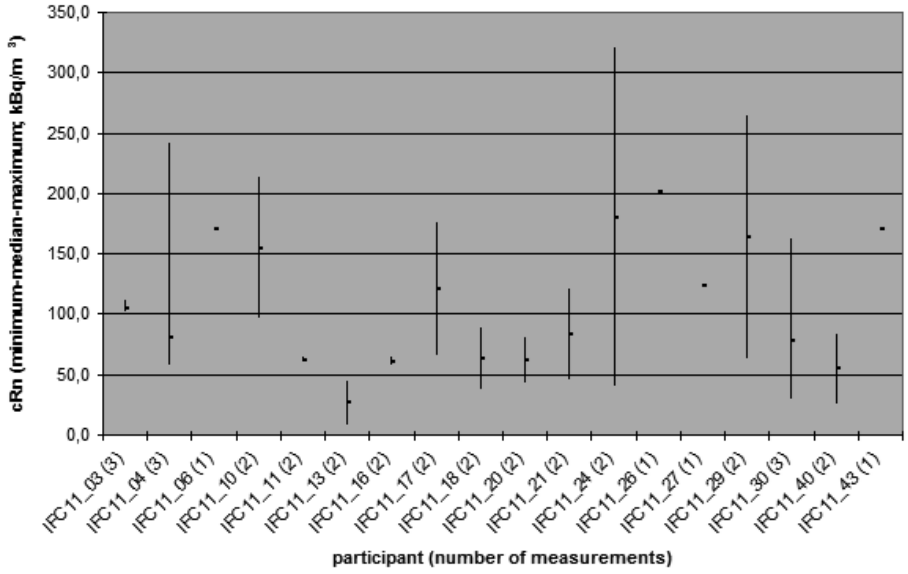

Figure 8 Intercomparison of soil-gas radon concentration data reported by different participants - surroundings of points E, G, CF, FG

If we exclude a part of the test site with local anomalies and if we evaluate only measurements performed in the surrounding of points A, B, C, D, F, H, AH, BG, DE, the agreement among participants is better. In this case, median values reported by different participants range from 13,7 to 77,4 kBq m^{-3} (median of reported median values was equal to 23,0 kBq m^{-3}).

Influence of variable volume of soil-gas samples

Unfortunately not all participants have reported the volume of soil-gas samples. Available data are shown in Figure 9. As can be seen, a larger variability of soil-gas radon concentrations is generally connected with sampling methods characterized by lower volume of soil gas samples (≤ 1 l). When the volume of soil-gas samples is larger (≥3 l), a smoothing effect is observed. On the other hand, if a larger volume of soil-gas sample is collected, small local anomalies of soil-gas radon concentration probably cannot be detected. Comparison of the methods characterized by a variable volume of soil-gas samples is problematical in principle, because very different targed volumes of soil are measured.

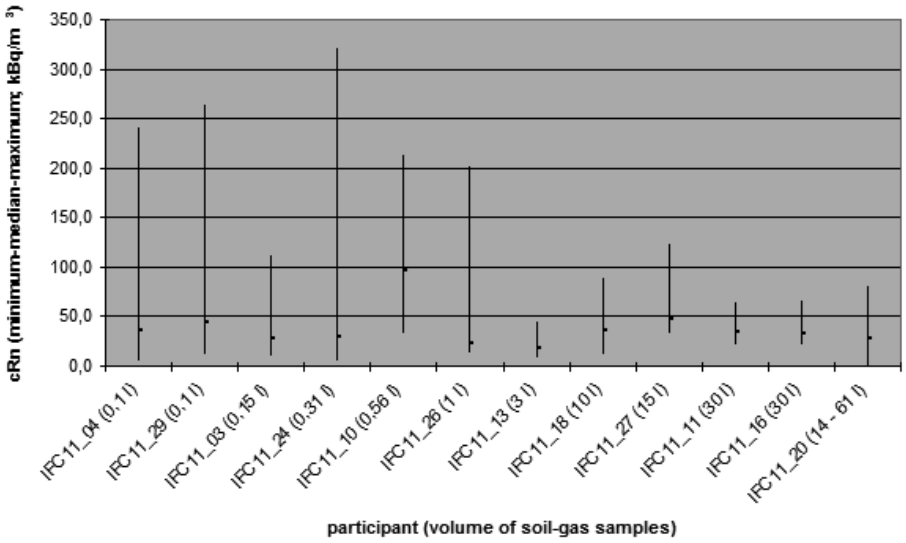

Figure 9 Influence of variable volume of soil-gas samples

Elimination of thoron

Information on the thoron elimination is incomplete again, only some participants have described the methods in detail. No elimination of thoron influence could represent one of reasons for a higher median soil-gas radon concentration reported by participant ICF11_10.

Conclusions

Geological conditions on the test site chosen for the soil-gas radon concentration intercomparison were not homogeneous. Local anomalies (substantially higher soil-gas radon concentrations) were observed in a part of the test site. The inhomogeneity probably represents the main reason for a high variability of reported data.

The quality of measurement protocols filled-in by the participants was also variable, very poor in

some cases. Many important data and information are thus missing.

As the distribution of data was not normal, median value of soil-gas radon concentration reported by different participant was used as the main statistical parameter to compare the results. Median values ranged from 17,3 to 170,0 kBq.m-3. If only a more homogeneous part of the test site (surrounding of points A, B, C, D, F, H, AH, BG, DE) was evaluated, then median values reported by different participants ranged from 13,7 to 77,4 kBq m^{-3}.

Other potential reasons for a relatively poor agreement among participants are following:

- Different number of measurements performed by different participants, ranging from 1 to 12. If there are some anomalies over the test site, a low number of measurements is not sufficiently representative.

- Variable volume of collected soil-gas samples, ranging from 0,1 to more than 30 l.

- Varying depths of sampling.

- In case of some participants, the method used did not allow to eliminate an influence of thoron.

- In case of some participants, no information of primary calibration of instruments was available.

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Appendix III: Scientific and technical comments of participants

The participants were asked to send to the organizers comments about the scientific and technical organization of the intercomparison. Their opinion is quite important and useful in order to improve this exercise in the next years. The result of the comments will also be used for the quality management of the organizers under the scope of ISO norm 9001. We resume here the comments receive at the moment of the production of this report.

Institution/participant: AUSTRIAN AGENCY FOR HEALTH AND FOOD SAFETY

Scientific and technical comments

We only sent our passive detectors for exposure but we were not in Spain ourselves. So we have little information on the methodology of the various parts of the intercomparison exercise and therefore cannot comment on this. Hope there will be a report which summarises the exercise procedures and the results.

Institution/participant: Federal Agency for Nuclear Control

Scientific and technical comments:

As to the test with passive detectors and soil gas measuring devices, I think (maybe I'm dreaming!) a two-step approach should be followed (a test under controlled conditions and one really under field conditions). I will try to explain:
For passive integrating devices fist of all an intercomparison exercise should be conducted in "lab" conditions (stable conditions as in a radon chamber). Only detectors with a "good result" (quality criterion as used in the past by NRPB) should then take part in a real field intercomparison. A special aspect we should think about and if possible come to some decision/agreement is what the purpose/role of transit detectors is and how its result will be used in the final result of the intercomparison exercise?

For soil gas measurements, I should follow a two-step approach:
a series of measurements in common holes (if there is no influence on the soil gas concentration by the gas extraction of a great number of participants) and then a second real field test (each one its "own" hole) for those with a "good" result.
The challenge for me is the set-up of an intercomparison exercise for active measurements: what quantities will be evaluated and how a kind of quality index can be defined? (there are quite popular integrating active devices - Ramons etc. and devices giving the temporal variations)

That are some of my reflections. I really hope that the field exercise done will lead to some discussion about the use of different tests and how to organize this the best way.
André
After the end of the exposure, normally a degassing for 3-4 hours is sufficient. Taking into account the great number of detectors and the fact that most of them are standing very close to each other, a longer degassing period in low exposure well ventilated conditions may be recommendable (some 8h period)

Institution/participant: RADON v.o.s.

Scientific and technical comments:

It is difficult to give comments having no information on the intercomparison results.

Some ideas:
(1) The number of participants as well as the number of parameters to compare were large. Maybe too large. But it is evident that the organizers have almost no chance to influence the number of participants. One way could be to require certificates on primary calibration (verification) of all measurement devices that are intended to be used in the intercomparison.
(2) In our opinion, it would be better to choose another test site for measurement of soil-gas radon concentration and of radon exhalation rate from the ground. Basic requirement: "more homogeneous" conditions at the test site.
(3) It would be probably better to separate the intercomparison of two above mentioned parameters: To start with the intercomparison of radon exhalation rate from the ground (1st day) and to continue with the intercomparison of soil-gas radon (2^{nd} day). When both parameters are measured together, there is a risk that an accumulator is placed on a hole remaining after soil-gas sampling.
(4) We would recommend to replace the stone table for measurement of radon exhalation from building materials from outdoors to the building - to decrease the negative effect of wind on measurement results. There is also a problem with a relatively low exhalation from the table - close to the detection limit of "common" measurement techniques. A material with a higher exhalation would be probably more appropriate for the intercomparison measurement.
(5)

Institution/participant: Bundesamt für Strahlenschutz

Scientific and technical comments:

The provided experimental set-ups are in general suitable to test measurement methods and devices under conditions comparable to real situations. Thus the intercomparison exercise contributes to improve the quality of measurements of the participating laboratories.
Technical comments:
The measurement data should be analysed with respect to the comparability of the conditions, especially the exposure conditions for the passive radon measurement devices. It should be discussed, if the results of the "transit" devices should be used to determine the effect of transportation and storage.

1 Concepts & basics

The question of qualifying a measurement system can be divided into two conceptually somewhat different partial questions, which relate to the fact that any measurement is the result of two physical processes: the observation process and the process which one wants to assess through observation. QA means (1) control, to an utmost extent, over the observation process, and (b), the ability to produce accurate (the meaning of which needs to be defined in actual cases) estimates of the investigated process.
Intercomparison exercises are meant to serve both ends. The difference to intercalibrations is, that passing the latter is usually seen as a condition to reasonably participate in the former, and that more emphasize is given to coping with realistic, in our context, environmental situations; instead, the focus of intercalibration is the observation process, while keeping the observed phenomenon rather simple and well controlled.
This leads to two conceptually different, but of course closely related questions:
A. How well does an individual measurement system (consisting of a sampling procedure (incl.

sampling design) and devices, i.e. sampling tools and monitors) perform in comparison with others and / or with a reference system, under given conditions?

B. How well are these given conditions assessed by an individual measurement system?

These conditions, i.e. the true state Z of the natural system which one observes, are inevitably known only to a degree. In general they are subject to temporal and spatial variations, that is, Z is a function Z(x,t).

Measurements are performed over spatial and temporal intervals, such as an area U centred on a point x and having extension d, and during a time interval T between t_1 and t_2. A measurement therefore measures the state Z(U; T), which is to be understood as some integration over Z(x, t), x□U, t□T; not necessarily the mean.

This implies the following problems (among others, possibly), relating to:
I. observation errors and resulting uncertainty of the result;
II Variability of the observed process, and its incomplete knowledge.

I. Observation process
Let the observation process by a certain measurement system (j) be called f_j. The measurement result generated by system (j) is therefore a value $z_j = f_j(Z(U;T))$.
The observation process includes random and systematic errors. Random errors can be understood as samples from a distribution F_j such that $z \sim F_j(Z)$. They depend on factors like detector sensitivity or mechanical properties of sampling and sample treatment tools (like weighing uncertainty, possible deformation of a core sampler etc.). Systematic errors or biases can result from these sources:

1 Calibration uncertainty and error (a random error of the reference value emerges as systematic error of a measurement based on that calibration);

2 Particular measurement protocols, i.e. a rule which defines how an “ideal” quantity is being quantified through a procedure. The condition to a protocol to be correct is to deliver consistent results: consistent between measurement results (i.e., same conditions □ same result up to statistics) and appropriate to what the purpose of the protocol is (e.g. set accuracy margins). Different protocols can deliver different results for identical conditions, without being “wrong”: only the functions f_j are systematically different. This consideration is less relevant for indoor, but more so for soil Rn assessment.

3 A possible influence of the observation process to the observed process. Examples: (a) if the observation process of indoor Rn implies opening the door of the room in which one measures, the concentration in the room necessarily changes. (b) A soil sampling tool always modifies, to an extent, the soil environment and hence the Rn concentration in soil.

II. Observed process
Since the process Z varies over space and time, results of the same measurement system are evidently different, in general, at two locations U(1) and U(2) and at two different times, T(1) and T(2). (U(i) and T(i) may differ in their locations and interval sizes.) System (j) thus delivers values $z_j(1)$ and $z_j(2)$, in general different also apart from measurement statistics.
Two different systems (j) and (k), located at different places and / or measuring at different times, generate results $z_j(U(1),T(1))$ and $z_k(U(2);T(2))$. If one wants to compare z_j and z_k, one obviously has to separate the effects of different devices (j and k; see above, I.) from the different conditions Z (i.e., U(1),T(1) and U(2),T(2)). The common solution is to keep Z constant (as well as possible) over □ > T and □ > U. This is done in classical intercalibration exercises. In practice this means that

Rn concentration in a calibration chamber is kept constant for a period, and changed in a controlled way; for spatial exercises, like for Rn in soil, as done in the periodic exercises in the Czech Republic, one tries to characterize the test field as a whole, and the near vicinity of the test points in particular, as accurately as possible.
In the opposite case, viz. Z(U,T) not constant between varying U and T, comparison of different measurement systems becomes difficult, with respect to both questions A and B.

2 Situation at the LARUC intercomparison facility, Saelices El Chico

2.1 Indoor radon

Three rooms in a former administration building in the mine area were identified as showing distinct Rn levels, in average. It has however turned out that the concentrations are difficult to regulate, since they appear to depend, to a high degree, on meteorological conditions which can be extreme at this site which is quite exposed to weather. Also the building (about 25 years old) has not been designed for keeping indoor atmospheric conditions controlled; finally interference by the measuring procedure itself (opening the door, possibly modifying the atmosphere in the rooms) appeared a major factor. The result is quite erratic, and difficult to predict and to interpret time series of the Rn concentrations.

2.2 Soil radon

The selected meadow, near the entrance of the mine and about 1000 m² large, has the advantage of electricity available and shady trees (an asset in that climate!), but is spatially very heterogeneous in soil properties, notably humidity, possibly mineral composition, and permeability, and as a result, also in Rn concentration in soil air. This means that spatial variability is such that is appears difficult to define even small vicinities – i.e. the present sampling "points" – with reasonably constant Rn concentrations. The high permeability in some zones of the meadow moreover leads to high temporal variability because of the influence of above-ground air to the Rn conc. in air in deeper layers.

3 Consequences for the design of an intercomparison exercise

Coming back to the initial questions A and B of section 1, this means that they have to be asked in a way that an intercomparison is meaningful, given the objective conditions which are controllable to some degree only. To answer the questions, as for example the ones proposed below, one would have to develop (or rather adapt existing) statistical indicators, which are able to qualify a result with respect to the question.

3.1 Indoor radon – long-term

Question of the exercise: How well is a long-term integration method (TE in this case, integration over days or weeks) capable to estimate a temporal mean of a strongly variable indoor concentration?

With respect to question A, this requires that all participants are subject to the same time series, which means (1) that all start and end exposure at exactly the same time, and (2) that no additional spatial variability within the room exists. (1) is essentially a matter of logistics, while (2) has to be tried, e.g. by installing sufficiently strong fans which provide sufficient mixing of the air; possibly identifying Rn sources and sinks and avoiding positioning detectors near them.
As to question B, it means to set a reference method which is able to capture the true series Z(t) with sufficient precision, from which any temporal mean can be calculated. This leads to a trade off

between sampling interval and counting statistics: longer sampling interval mean better counting statistics but worse temporal resolution, and vice versa. The optimum can only be found be a series of experiments and depends on expected Rn levels (influencing counting statistics) and expected temporal gradients (affecting the importance of temporal resolution). For setting a reference against long-term methods one would probably choose lower resolution, as long as it is large compared to the integration time of the tested devices, and better statistics.

3.2 Indoor radon – short-term

Question of the exercise*: How well is a short-time (or almost real-time) system able to capture the dynamic?*

This depends basically on the inertia of a system (e.g. due to diffusion time into, and out from a closed system) and factors like memory effects, e.g. due to the presence of longer-lived decay products remaining from a high-concentration episode, which disturb measurement during a following low-concentration one.
As to question A, this means again that spatial variability should be avoided, while coinciding start and end times appear less relevant.
For question B it obviously means, in addition to what has been said in section 3.1, that the reference method must be controlled very carefully for such effects. The trade-off between measurement accuracy and temporal resolution is particularly delicate here.

3.3 Soil radon - level

The situation appears more complicated here because there is little which can be done to influence the soil concentration in a way which is to some extent possible in the indoor case. Also, replication at *exactly* the same location is not possible because once a bore hole is set, the soil is not any more in its original condition. This is a critical issue in a situation of high spatial variability, since the minimum distance between bore holes to be called essentially independent, about 20 cm (or more ?), may be too large to call them the same sampling point in case of high spatial gradients.

One may therefore resort to “partial” intercomparisons, as we already started discussing during the exercise. Two ways appear feasible; 3.3 and 3.4 are essentially the spatial analogues to 3.1 and 3.2 in temporal setting.

Question of the exercise: How well is a system able to estimate the Rn concentration in soil, in a given bore hole?

The organizers would establish a number of fixed boreholes, representing a reference protocol of soil air sampling. The participants would use these for sampling. This way everybody would sample on exactly the same location, that is, $U^{(i)} = U^{(j)}$, but the intercomparison would be restricted to comparing the sampling procedure except producing the borehole. (To some extent, but in an uncontrolled way, this has actually been done at the exercise, as some participants took advantage of the fancy Portuguese drilling machine.)
For question of type B, it means, of course, that the reference method must be calibrated and tested very carefully.

3.4 Soil radon – pattern

Secondly, one may be interested in testing the capacity of a system to delineate zones of an area (i.e. the test meadow) with high and low radon potential (or more classes; to be defined as

appropriate to the local situation):
Question of the exercise: How well is a system able to capture the spatial pattern of the Rn distribution in soil?

A participant would produce individual bore holes at deliberate locations and measure using his or her method. If available quickly, as some methods allow, given the results, the participant would decide where to set the next sampling point, thus coming to spatial information in an iterative way. (Also proxies which are easier to acquire, such as dose rate at the surface, may be useful to decide this.) If results are not available quickly the participant would probably decide for a proxy method to set sampling points, or to a defined grid which is deemed optimal for assessing a pattern.
The recovered patterns would be compared; a suitable statistic has yet to be identified or developed, adapted to questions of types A and B.

Again leaving aside temporal variability, comparison of methods between them, and against a reference method, could be performed in the following way, which is however more demanding and has never been tried, to my knowledge. Practicality is not certain and would definitely require a series of experiments.
In theory the ability to assess spatial variability can be quantified with the ability to estimate a spatial covariance function (or the related variogram),
$C(h) := \mathrm{cov}(Z(x), Z(y))$, $h:=|x-y|$ (distance between points x and y).
An empirical covariance function c(h) may be compared with the "true" one (as found by a very careful and dense survey – this would refer to question B), but this is not statistically trivial.
Relative performance may be assessed by estimating cross-covariances between participants, say (i) and (j),
$C^{ij}(h) := \mathrm{cov}(Z^{(i)}(x), Z^{(j)}(y))$.
One (i) may of course be the reference method, $Z^{(0)}$. Apart from the statistical challenge the exercise would be more time consuming as at least 30 – 50 sampling points are necessary for a reliable estimate of the covariance (or the variogram).

Suggestions for the future of LNR

The unexpectedly large number of participating laboratories showed that there is a great interest to test and validate methods and devices for the measurement of natural radioactivity under realistic conditions. We would like to encourage the colleagues from LaRUC to advance the exercise considering the comments of the participants.
In case of so many participants we would recommend to improve the timing of start and end of exposure. Possibly it would be preferable to do the measurements with passive devices without presence of participants and visitors to keep the building in a somewhat "calm mode".
Ideally the passive radon measurement devices, which are used to determine the effect of transportation and storage ("transit" devices), should be stored in a room with low radon activity concentration and with climate conditions comparable to the rooms, where the other devices are exposed.
The work at the test house at the uranium mine, where they are testing the possibilities and results of measures to reduce the indoor radon concentration, should be continued.

Institution/participant: University of Pannonia

In the case of the soil gas measurement the field conditions were not suitable to compare the results. The circumstances were inhomogeneous (uranium distribution in the function of distance of sampling point), there were too much root, the soil contains lot of stone.

Due to the hard sampling conditions the efficiency of the (mostly self developed) method was easily observed, which was very useful to upgrade the systems.

The measurement of radon concentration of the waste soil deposit could be more fortunate than the chosen site because of the homogeneous conditions. That place is suitable to compare the measured radon whilst the chosen field is suited for testing the sampling methods.
In the case of the gamma dose measurement the coverage of the original soil with sand was very important because the measurement of gamma radiation in low dose rate is hard to determine. In my opinion more selected points were be necessary in different fields/areas.

Suggestions for the future of LNR

There is another comment for the next event: If you attach GPS coordinates of the important places it can be greatly lighten the orientation on field or in case of the accommodation and so on.

Institution/participant: **Università Europea di Roma**

Scientific and technical comments:

Does your work group intend to issue a publication with all the groups' reports about the exercise or could we send a call for papers to all participants for that? Publishing not only the data but also a description of methods and procedures would be extremely valuable for further work in the field and we would be glad to support such an initiative, so please let us know.

Institution/participant: **NRPA**

Scientific and technical comments:

We both enjoyed your accomplishment of the intercomparison! Very well done! We enjoyed the combination of lessons in the morning and practice work after. Very nice city, location and people!

Passive detectors
The door was open too much during day one in Room 1. It will be better with more control of the radon concentration in the future. For instance you can gate people through a small room and then into the calibration room. The radon concentrations in the calibration room have to be homogeneous and must be checked out before start.

Radon in water
One more barrel of water with a different radon concentration.

Only one negative remark. When we visit the site we unfortunately experienced that the radon concentration was not homogeneous in room1. That is very important in intercalibrations.

Institution/participant: **Laboratory of Natural Radioactivity, University of Coimbra**

Scientific and technical comments:

For those using lab equipments for measuring radon in water, it could be useful to have the

possibility of receiving samples by mail. For radon exhalation measurements maybe it could be prepared a flat ground with homogeneous and moderately exhalation that allows in a couple of hours to register significance radon concentrations in the containers.

Suggestions for the future of LNR

Sessions for discussion methods and results could be extended for example to all morning, leaving only one part of the day for practical measurements

Institution/participant: IFIN-HH, Bucharest

Scientific and technical comments:

We only sent our passive detectors for exposure as unfortunately we could not come to Spain ourselves. It is our first international intercomparison exercise so we cannot compare with previous experience. We would have found useful some printed information (on file/email) on the actual methodology of the various parts of the intercomparison exercise, as not being there we missed the details.
Due to this lack of information we first made a mistake by mixing up two of the exposures (time/concentration data), which was cleared afterwards.
We cannot comment on more details of the exposures, but we think that it is extremely useful to get an overview of comparative results on the same radon concentration obtained by many participants, provided the uniformity of the field is known with a given accuracy.
The weakest point causing some confusion to us was the contribution of the transit detector, where no previously established methodology was given, so we did the estimation of that contribution by our best judgement. This is by its nature variable, due to the possibilities of transfer, various routes of travel etc., so it is important to evaluate the effect of this contribution in the final result.
On the other hand a similar disturbing factor would appear also in field measurements as well, so a discussion of it might be useful.
We are looking forward to the final report summarizing the exercise procedures and the results.

Suggestions for the future of LNR

An option for a better knowledge of the uniformity of the fields used for the exercise would be a previous mapping of the area, if feasible. Using controlled spaces (radon chamber) ensures better control, but is it “field conditions” then?
Definitely I would vote for more descriptive materials available (electronically), also would be nice to have copies of the contributions to the lessons/talks, both for those who were present or couldn’t attend.

Institution/participant: INSTITUTE OF NUCLEAR PHYSICS PAN, Laboratory of Radiometric Expertise, Poland

Scientific and technical comments:

The idea of such intercomparison measurements under natural field conditions is very valuable and worth continuing. Especially, measurements of gamma dose rate in real environmental energy spectrum were important. In our opinion this is the best way of that kind of comparison.
The meeting was a good opportunity to see and discuss different techniques. In this way teams can improve their own methods and exchange experience.
It is obvious, that analysis and comparison of obtained results are not easy. The conclusions should be drawn carefully taking into account many factors influencing field measurements.

Suggestions for the future of LNR

1. Before field experiment all participating teams should prepare short descriptions of the applied methods (equipment, measurement technique, method of result calculations) and share with others e.g. by e-mail. The first day of intercomparison should be devoted to present the teams and applied by them techniques + discussion.
2. Soil gas radon – test site should be much more homogeneous as regards radon concentration; if possible it should be earlier measured several times to obtain a kind of "target value" (see Czech experience – reference sites). We have experience with long-term measurements of radon in soil on our test site using track detectors and active method. The measurements lasted two years and we obtained monthly average radon concentration in 10 points (in regular grid). This idea might be applied for LNR site.
3. In our opinion, the model test site for soil gas radon should be equipped with permanently mounted soil probes in 3-4 chosen points. All teams should take soil gas samples to their devices from these probes. Of course, this means that the experiment could last more longer than one day because some time is needed between samplings.
4. The measurements of radon exhalation rate should be separated in time (or in place) from radon in soil points.
5. During exposures of passive detectors it is necessary to ensure homogeneous radon concentration in the room during all the time of experiment. The insertion of strong radon source in one place of the room could have resulted in misstatement of some of the obtained results.
6. The very good idea was preparing one template (xls format) for sending the results of measurements.

Institution/participant: **Universidad de Santiago de Compostela**

Suggestions for the future of LNR

Perhaps it was more operational in time separating the intercomparison of passive detectors and continuous.

Institution/participant: **HPA**

Scientific and technical comments:

I thought that the intercomparison was particularly valuable for the chance to compare active radon measuring instruments, which does not often occur. Large numbers of instruments were exposed simultaneously to varying radon concentrations, as found under real exposure conditions. The results from this will be very interesting. Preparing a report on the intercomparison will be a large piece of work, but is very important to allow participants and others to learn lessons from it. I suggest that to avoid publication delays, it would be helpful to issue reports separately for passive detectors, for active radon detectors, for soil gas measurements, etc. The 'transit' passive radon detectors will have received radon exposures that were not negligible. It is important that participants report how they took transit exposures into account when calculating laboratory exposures.

Suggestions for the future of LNR

I think it would be valuable to repeat the LNR, possibly at intervals of two years. The most important part from my point of view is the intercomparison of active radon monitoring equipment.

I would expect the intercomparison of passive detectors to be less important, because there are already laboratory intercomparisons held by HPA, BfS and NIRS. But I don't know what issues may arise from the current intercomparison, relating to exposures under field conditions. It may be that issues are identified that would be resolved by a further passive intercomparison at LNR. If this is repeated, I suggest that a low-radon facility, such as drums half-full of activated charcoal, could be provided for transit detectors.

Radon in indoor air by passive detectors: were blower fans used in the exposure rooms to improve mixing of the air in the rooms? If not, this could be included next time.

Radon in water:

a. The order of participants taking samples from the water barrel should be noted, as well as the volume of water taken by each, to check if a trend can be observed as liquid is removed from the barrel.

b. As liquid is removed from the barrel, what is replacing that volume in the barrel? If air, then radon will outgas into the air above the liquid in the barrel, changing the activity concentration in the water.

c. What methods do the participants use to address potential problems of radon outgassing from the sample water into any headspace in their sample containers? This is a useful item to include in the exercise questionnaire.

Appendix IV: Pictures of the laboratory LNR

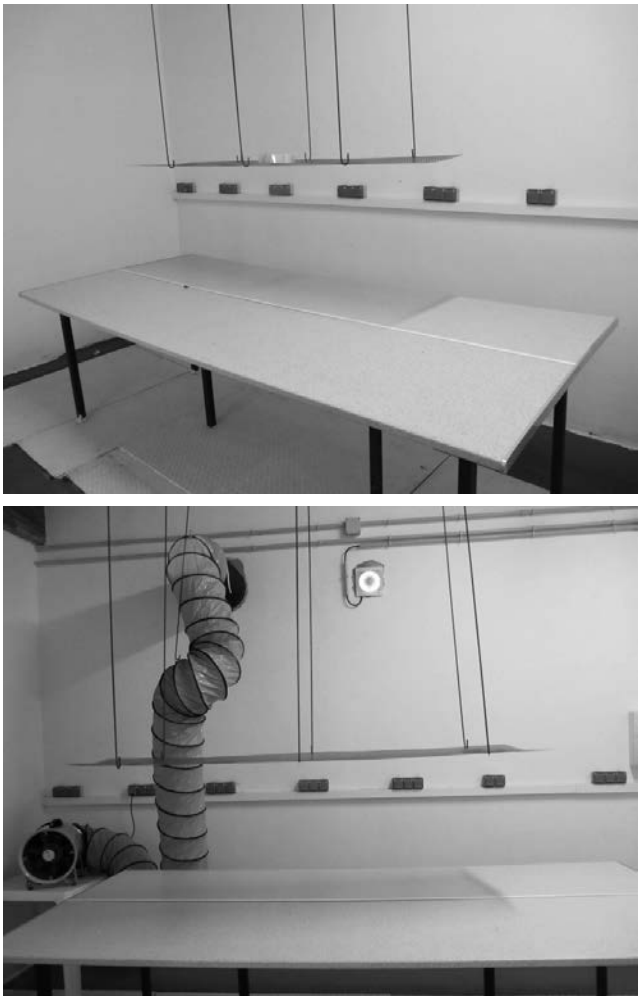
LNR Main building

Severiano green. Place used for external gamma dose rate intercomparison with a reference level of 110 nGy h^{-1}

Area for measuring exhalation rate from building materials

Main entrance of LNR with two rooms used as natural radon chambers on the left

Two views of interior of the radon chambers. One of the chambers has an electrical fan which allows decreasing the radon level indoors. These rooms were used for exposures 1 and 2



View of the radon chamber located in the first floor. Exposure number 3 was carried out in this room.

Working area located on the ground floor. It is possible to organize approximately 30 working stations. Each participant presented during the intercomparison exercise used its own working station located in this ground floor

Area for radon in water. It has a capacity for 10 working stations extra

Conference hall located in the first floor of the building

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