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BOOK of ABSTRACTS

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Foreword

The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences has been organizing since 2000 the serial conferences, traditionally called **RADON IN THE ENVIRONMENT**. In 2000 and 2005 there were national conferences. This is the second international meeting; the previous one took place in Zakopane, Poland (2009). Research on radon and its progeny has been conducted all over the world for many years. Last year the new European Union Council Directive 2013/59/Euratom was launched that lays down Basic Safety Standards (EU BSS) for protection against the dangers arising from exposure to ionizing radiation. Under the new Directive radon takes on particular significance. Thus, we hope that our conference will be a helpful scientific meeting for all participants.

However, we also hope that we will find time and nice places in Krakow to meet together and establish not only radon cooperation but also new friendships.

Jadwiga Mazur, Krzysztof Kozak
on behalf of Organizers

ORAL PRESENTATIONS

Invited Talk

THE RADON LEVELS IN ISTRIAN PENINSULA

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Long-term indoor radon measurements performed by LR-115 track etched detectors in Croatian homes during 2003/2004 showed the arithmetic means of radon concentrations in Istria County were slightly higher (76 Bq/m^3) than in houses at national levels (68 Bq/m^3) [1]. The detectors were randomly distributed depending on population density and many of these detectors were exposed in houses in the cities at the coast. Because of the geological structure of Istrian peninsula which mainly consists of a limestone that is characterized by karstic topography on its surface, it is expected that there are areas with elevated radon levels in soil gas as well as inside buildings above (e.g. houses, kindergartens, schools). Recently, from the autumn of 2013 until the spring of 2015, the radon measurements at more than 1000 randomly selected locations (in houses as well as in schools and kindergartens) were investigated. The obtained results will be presented and discussed.

Radon concentrations in soil gas in Istrian peninsula were measured in November of 2013 and 2014 and February of 2014 and 2015 with the AlphaGUARD and RM-2 measuring systems. The obtained average value of 103 kBq/m^3 classifies the soil of Istria County, according to the used soil classification [2], into soil of high geogenic radon potential. It is important to emphasize that there are area with radon concentrations up to 500 kBq m^3. In accordance with the obtained results the areas with elevated indoor radon levels as well as levels of radon in soil gas were identified and radon maps were generated using different geostatistical approaches.

Radon concentrations in the municipal water supply systems were also measured with AlphaGUARD system using procedure for quick determination of radon values. The highest measured value was 5.6 Bq/dm^3 and is much lower than the usual reference level of 100 Bq/dm^3.

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[2] Radolić V., Miklavčić I., Stanić D., Poje M., Krpan I., Mužević M., Petrinec B., Vuković B. : Identification and mapping of radon-prone areas in Croatia—preliminary results for Lika-Senj and the southern part of Karlovac Counties ; Radiation protection dosimetry 162(2014)1-2, pp.29-33.

Invited Talk

RADON: A GOOD TRACER AND AN INVISIBLE ENEMY

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Radon can be used as a naturally occurring tracer for a wide variety of environmental processes. By means of grab-sampling or continuous monitoring of radon concentration, and together with information coming from other indicators, is possible to assess several types of dynamic phenomena in air and water.

This presentation will show a brief review of the abovementioned use of radon and its progeny. As a first example, radon can be an atmospheric dynamics indicator, related with air mass interchange near land-sea discontinuities as well as for the study of vertical variations of air parameters.

Concerning indoor gas behavior, some results of the studies related with ventilation characterization performed in the Altamira cave (Cantabria , Spain) will be shown. Radon concentration changes were used as valuable indicator of the atmospheric dynamics inside the cave, providing essential information for the conservation of prehistoric paintings with more of 16000 years old.

Also variations of radon concentration in soil and underground water can provide relevant information about different geophysical phenomena. Nowadays the correlation between radon variations and seismic activity poses an active research field. The joint analysis of radon changes in water together with monitoring of parameters like electrical conductivity, pH, CO_2 and temperature provide information suitable to contribute to the establishment of reference conditions concerning seismic activity of a given area. In relation with this topic, some preliminary results obtained in thermal spa will be shown.

Finally, dose to workers by inhalation of radon are evaluated and for different workplaces are compared with the recommended values coming for ICRP Publications.

Invited Talk

RADON PROBLEMS IN MINING AND POST-MINING AREAS IN UPPER SILESIA REGION, POLAND

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The results of the radon studies, performed in the Upper Silesia Region in Poland, have shown that radon indoor concentration levels depend first of all on the geological structure of subsurface layers. The essential factors, influencing radon migration ability, are mining-induced transformations of a rock mass. In some cases, significant variations of radon potential have been found at sites, located on similar geological structures and experiencing comparable mining effects.

In areas of significant deformations of the strata we observed easier migration and exhalation of radon from the ground caused by:

- activation of old faulting zones, what may additionally increase radon risk;
- disintegration of rock body over zones of historical shallow exploitation;
- particularly intense damages of strata in areas of overlapping of historical shallow mining and current deep exploitation of hard-coal;
- damages of constructions due the surface subsidence, creating pathways for easier radon migration into buildings.

We estimate, that in specific zones as described above, radon levels may exceed 300 Bq/m^3 in about 2% of dwellings.

Another problem, that may appear in post-mining areas, is related to the reclamation of radioactive contaminated areas. For example, significant radon exhalation from settling ponds of mine waters is often observed due to enhanced radium content in bottom sediments. This problem is more important, when concentration of radium isotopes in sediments is high due to discharge of radium-bearing waters into such ponds. The removal of bottom sediments from such ponds and/or reclamation of these reservoirs may lead to creation of zones with high radon potential.

As described above, a complex geology of the strata in Upper Silesia, the mining activity in the region and additionally the discharge of radium bearing waters into environment are the most significant factors, affecting radon potential and hazard in dwellings in this region.

Invited Talk

THE CONCENTRATIONS OF ENVIRONMENTAL RADON IN CHINA

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Since 1980s, several nationwide or sub-nationwide surveys on indoor radon concentrations have been carried out in China. In each survey, ^{222}Rn concentrations in several thousands of rooms were monitored by using active or passive methods. The results indicate that the average indoor ^{222}Rn concentration has significantly increased in the past 3 decades. The main reasons for the increase are considered as the change of life style and the use of new types of building materials. Besides of the ^{222}Rn surveys, indoor ^{220}Rn concentrations were also investigated in some rural areas. It was found that the exposure to indoor ^{220}Rn and its progeny was nearly the same or even exceeded of that of ^{222}Rn and its progeny in some special dwellings or areas.

In recent years, the exposure to radon for several millions of non-uranium miners has also aroused the governmental concern. ^{222}Rn surveys in about one hundred of non-uranium mines have been carried out. It was found that the concentrations largely varied with the mine types, and the concentration higher than 1000 Bq·m^{-3} could still be observed in some metal mines. Besides of ^{222}Rn surveys in mines, several outdoor surveys have also revealed that the levels of outdoor ^{222}Rn are increasing in some regions due to the TENORM.

As the large number of population and the vast territory, it is still hard to estimate the risk of radon in China. However, several projects have been scheduled to assess the potential risk and to control of radon in China.

A01

RADON CONCENTRATIONS IN SCHOOLS AND IN DWELLINGS: A STUDY ON ASSOCIATION, CO-REGIONALISATION AND BIVARIATE MODELING

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Most indoor radon (Rn) surveys concentrated on residential Rn, so far. People spend, however, significant part of their lifetime at work, in places different from home. Thus, Rn exposure at work places can contribute importantly to overall Rn exposure. Consequently, new Rn regulations such as the European Basic Safety Standards, emphasize limiting Rn exposure at work alike the one at home. A particularly important workplace is school, equally for students as for teachers and other staff. Several countries, therefore, started early with surveying Rn in schools and kindergartens. In addition, sampling schools is logistically simpler than residential surveys, so that school surveys may serve as surrogates of residential Rn surveys, which are far more demanding on resources.

One largely open question is, whether or to which degree there is a spatial relationship between Rn concentrations in schools and in homes. If there is one between these variables, it would allow estimating one from the other, or using both in joint spatial estimation. For physical reasons – because home and school Rn have partly the same sources, namely the ground below the buildings – one would expect that such relation or association exists. Other sources and controlling factors, specific to schools and homes and different between these types of buildings, may however obscure the relation. A further cause, which contributes to concealing that relation, is that naturally, schools and homes cannot be located at the same site, but in some distance from each other, over which the geogenic control can also vary. In fact, it is known that the geogenic radon potential is subject to high small-scale variability. The resulting problem of "non-collocated data" renders the analysis particularly complicated and affords specific statistical techniques.

In this contribution, we investigate four georeferenced bivariate (home, school) datasets with this respect: one originating from a pilot study in Sokobanja district, Serbia (where statistical association of the variables has been demonstrated); a dataset from Macedonia; one from Banja Luka, Republika Srpska, and one of a regional school survey in Upper Austria together with the values of the Rn potential (standardized residential indoor concentration) in that region.

As methods of spatial analysis applied to recover statistical association of spatially non-collocated variables, we apply different techniques, among them nearest-neighbour association, correlation of spatially aggregated means, cross-variography and categorical association. If successful, the result can be used for bivariate cross- and co-estimation of the variables.

We demonstrate methodology and first results, which show that the statistical association is not quite easy to recover. Weak association has the consequence that estimation of one from the other implies high uncertainty. We also propose physical reasons for our findings.

A02

THE POSSIBLE IMPACT OF WEATHER CONDITIONS ON INDOOR RADON CONCENTRATIONS

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The indoor radon concentration of a specific building can exhibit large variations over short and long time-scales. A significant part of these variations are caused by factors related to specific equipment, such as heating and mechanical ventilations and human actions, such as opening doors and windows. These lead to the typical seasonal variations commonly observed in northern countries, where radon levels are usually higher during the heating season than in summer.

On the other hand it has been suggested that weather conditions might have a significant impact on indoor radon levels[1,2,3]. In order to further investigate the possible extent of this impact, we have started the continuous monitoring of indoor radon concentrations and weather conditions in and immediately outside a former schoolhouse in the Swiss Plateau at the beginning of 2014. The aim is to investigate which weather parameter has the strongest influence and to understand how the exhalation of radon gas from the soil might be regulated by the surrounding conditions. The building in question is not used regularly anymore and the radon measurements are performed in a space below the stairs with natural soil and mostly unaffected by human influence. A weather station is setup 20 meters from the building and records all relevant weather data hourly.

We find evidence that the outdoor temperature has the strongest impact on the indoor radon level. During the cold season (October-March) the indoor radon level can be well fitted by a quadratic function, with the outdoor temperature as only free variable. During the warmer season the indoor radon level is continuously increasing from April through September, even though the outdoor temperature range is rather small. We suggest that the soil temperature might have an influence and that its increase in summer causes less radon exhalation outdoors and therefore more radon exhalation indoors. In order to test this possibility we have started to measure also the radon level in the ambient air. The aim is to find an opposing trend of indoor and outdoor radon levels as a function of outdoor temperature.

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A03

DOSE ASSESSMENT DUE TO RADON EXPOSURE IN DWELLINGS, SCHOOLS AND KINDERGARTEN

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Radon concentrations measurements were performed in 40 dwellings, 35 elementary schools and 5 kindergartens in 3 municipalities in Republic of Macedonia by two types CR-39 nuclear track detectors. In the dwellings, the measurements were performed with detectors commercially named RSKS for one year period from June 2013 to May 2014 in the most occupied rooms of the buildings: living room or bedroom. The detectors type Gamma 1 were exposed for the same period in the kindergartens playroom or bedroom. The measurements in schools were performed in one classroom with paired Gamma 1 detectors. One detector was exposed during the same period as detectors in the dwellings and kindergarten and other in the period of the school year duration, starting September 2013 to May 2014. In order to check reproducibility of the results paired RSKS and Gamma 1 detectors were exposed in five schools. We accepted equality of the results at 95% confidence level.

The distribution of the measured data in all observed buildings was well fitted by lognormal function. The geometric mean values of radon concentrations obtained for dwellings (129 Bq/m^3), schools (127 Bq/m^3) and kindergartens (125 Bq/m^3) in these municipalities were higher than country average radon concentration (84 Bq/m^3) reported in national survey. Taking into account different occupation time the estimated annual effective doses due to radon exposure were found to be 3.3 mSv in dwellings, 0.8 mSv in kindergartens, 0.4 mSv for teachers in schools and 0.3 mSv for children in schools. We obtained that different exposure time of detectors in schools did not influence annual effective dose for teachers and children.

A04

RADON GENERATION AND DECAY FROM SOIL AND GROUNDWATER OF BUDHAKEDAR REGION, GARHWAL HIMALAYA, INDIA

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Radon enters in the environment through diffusion and transport from the soil and ground surface. Atmospheric radon is considered to be the most effective element of health risk. Diffusion of radon through soil is strongly affected by the degree of water saturation of the soil pores. This paper reports the radon emanation power of soil samples in Budhakedar area of Garhwal Himalaya, India. The formulations are applied to the experimentally measured radon data from soil of the study area. The estimated rate of generation and decay of radon in Budhakedar area ranges from 6.8×10^{-5} $Bq.m^{-3}s^{-1}$ to 89.9×10^{-5} $Bq.m^{-3}s^{-1}$ and 1.4×10^{-5} $Bq.m^{-3}s^{-1}$ to 42.9×10^{-5} $Bq.m^{-3}s^{-1}$, respectively. The quantity of radon present in soil or in groundwater depends directly on trace concentration of radium in the earth's crust. It is observed that the total generated radon in soil of the earth crust is more than the decay of radon in the same medium. The generation and decay of radon can be described with the traditional single phase diffusion advection equation. Generated radon values are validated with the radon emanation rate measured by plastic track detector (LR-115 type II) technique for two different seasons of a year.

***Keywords*:** Radon; Generation; Decay; Groundwater; Soil-Gas

A05

FACTORS UNDERLYING PERSISTENTLY HIGH RADON LEVELS IN A HOUSE IN A KARST LIMESTONE REGION OF IRELAND

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The remediation of buildings with elevated radon concentrations is generally straightforward. However, in some cases a number of attempts may be needed to reduce concentrations to below the reference level and, occasionally, it may be impossible to reduce concentrations to below the reference level in a cost effective way. This paper details the work carried out between 2004 and 2012 to reduce radon concentrations in a house with initial radon concentrations of almost 1500 Bq/m^3. Over this period high radon levels were consistently recorded despite the introduction of various radon remedial measures. Remedial work was carried out on 10 occasions with 29 radon tests carried out to measure the effect of this work.

The paper describes the structure of the house and the karst geology that it is built on and the likely contribution of these factors to the difficulties encountered reducing concentrations. Ultimately, radon concentrations were reduced to about 450 Bq/m^3 but no further reductions were considered practicable without substantial and costly renovation to the house. Nonetheless, the remedial work carried out to date has resulted in a significant reduction in the risk to the homeowner of developing lung cancer. This work has also added to the understanding of radon remediation techniques in Ireland particularly for houses built on karst limestone.

A06

NATURAL RADIOACTIVITY SURVEY ON SOILS ORIGINATED FROM SELECTED SITES OF THAILAND AS POTENTIAL SITES FOR NUCLEAR POWER PLANTS FROM RADIOLOGICAL VIEWPOINT

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Surface soil samples were collected from selected provinces in the southern part of Thailand as potential sites to set up thermal and nuclear power plants. Concentrations of ^{238}U and ^{232}Th were determined using inductively coupled plasma mass spectrometry (ICP-MS) and gamma spectroscopy with HPGe (High purity germanium) detector was used for ^{40}K determination. Activity concentrations ranged from 4.4–121.9 Bq kg^{-1} for ^{238}U, 5.8–169.7 Bq kg^{-1} for ^{232}Th and 5–1422 Bq kg^{-1} for ^{40}K. The radiation hazard parameters were evaluated from activity concentration of ^{238}U, ^{232}Th and ^{40}K in accordance with the UNSCEAR 2000 report. The estimated doses due to external hazard indices as well as radium equivalent activity were below permissible limit.

R. Kritsananuwat, S. K. Sahoo, M. Fukushi, K. Pangza, S. Chanyotha: Radiological risk assessment of ^{238}U, ^{232}Th and ^{40}K in Thailand coastal sediments at selected areas proposed for nuclear power plant sites; Journal of Radioanalytical and Nuclear Chemistry, 303 (2015)1, pp.325 – 334.

A07

LONG-TERM MEASUREMENTS OF RADON, THORON AND THEIR AIRBORN PROGENY IN 25 SCHOOLS IN REPUBLIC OF SRPSKA

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This article reports results of the first investigations on indoor radon, thoron and their decay products concentration in 25 primary schools of Banja Luka, capital city of Republic Srpska. The radon and thoron measurements have been carried out in the period from May 2011 to April 2012 using 3 types of commercially available nuclear track detectors, named: long-term radon monitor (GAMMA 1), and radon-thoron discriminative monitor with nuclear track detectors (RADUET) while equilibrium equivalent radon concentration (*EERC*) and equilibrium equivalent thoron concentrations (*EETC*) measured by Direct Radon Progeny Sensors/Direct Thoron Progeny Sensors (DRPS/DTPS) were exposed in the period November 2011 to April 2012 . In every school the detectors were positioned at 8-10 cm distance from the wall. The obtained geometric mean concentrations were 99 Bq m^{-3} for radon and 51 Bq m^{-3} for thoron. Those for equilibrium equivalent radon concentration (*EERC*) and equilibrium equivalent thoron concentrations (*EETC*) were 11.2 Bq m^{-3} and 0.4 Bq m^{-3}, respectively. The correlation analyses showed weak relation only between radon and thoron concentrations as well as between thoron and *EETC*. The influence of the school geographical position and factors linked to buildings characteristic in relation to measured concentrations were tested. The geographical position and of floor significantly influence radon concentrations while thoron concentrations depend only from building materials (ANOVA, $p \leq 0.05$). The obtained geometric mean values of the equilibrium factors are 0.123 for radon and 0.008 for thoron.

Keywords: Indoor air, radon, thoron, primary schools, nuclear track detectors

A08

HYDROCHEMISTRY AND RADON ISOTOPES IN GROUNDWATER AND EMISSION FROM ROCK OUTCROP AROUND AREAS OF HIGH RADIOMETRIC ANOMALIES IN NE, NIGERIA

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High radiometric values were observed on aero-radiometric map of part of northeastern Nigeria and this might indicate abnormal occurrence of naturally occurring radioactive materials in the area. Information on groundwater radiochemistry is essential in the understanding of interaction between host rock constituents, groundwater quality and its fitness for consumption. Inhaled/ingested radon (gas) isotopes originating from soils and rocks and dissolve in ground water for example, can lead to health risk, just as deficiency or too much of some mineral elements in groundwater can be.

In this study, physico-chemical parameters of groundwater from the study area were determined together with radon and thoron gas to evaluate their implications on the worth of groundwater from the area for consumption. The study identified five water types (Mg-Ca-Na-HCO3, Mg-Ca-Cl), with percentage distribution of 45.7%, 22.8%, 14.28%, 14.28% and 2.85%, respectively. Mg-Ca-Cl water types indicate stagnant waters and are mostly unfit for consumption. Radon concentration (Bq/m^3) ranges from 731±4.9 to 84,300±530 with equivalent airborne radon contribution of 2.71 to 311.91 Bq/m^3, effective dose between 0.13 to 15.60 mSv/yr and a working level (WL) range of 0.09 to 4.39. Radon and thoron exhalation from aquifer materials in the area ranged from 62.5±4 to 150±10 Bq/m^3 and 12±4 to 1250±38 Bq/m^3, respectively. Water types and radon isotopes distribution were closely related to the groundwater flow pattern of in the area. High radon and thoron values in groundwater were mainly recorded in wells with very high hardness and equipped with hand pumps. Most of the water samples (68.75%) will contribute to airborne radon that will translate to a dose >1 mSv/yr standard set for the public.

Keywords: Nigeria; water type; groundwater flow; Radon/thoron; inhalation

A09

INFLUENCE OF GEOGAS SEEPAGE ON INDOOR RADON

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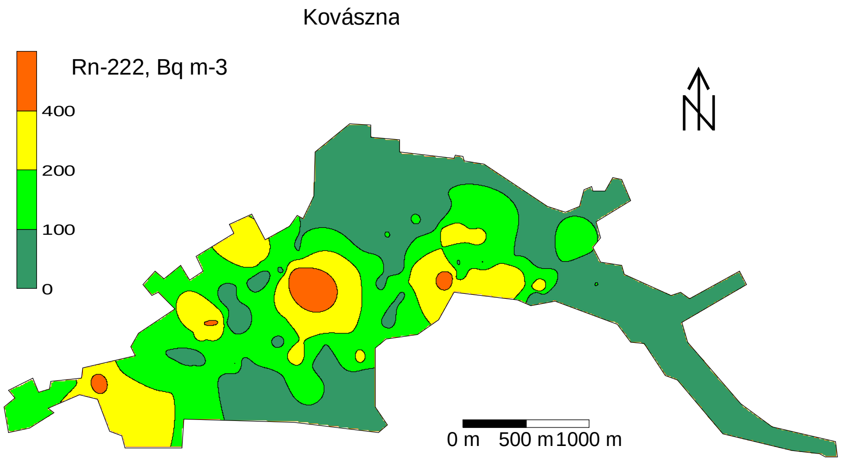
In most of the cases the source of elevated concentrations of indoor radon is the soil. Depressurized indoor environment sucks radon rich soil gas into the interiors of buildings through cracks and joints of the floor. On the other hand, overpressurized soil gas due to seepage of geogases can significantly enhance this process. Geogas efflux may have different origin, such as post volcanic degassing, metamorphic degassing and chimney effect on karst terrains.



In this work, we have done representative radon surveys for several settlements in areas affected by geogas seepages. We found that the presence of geogas seepage significantly increases the radon levels in houses situated in areas with enhanced soil gas exhalation rate. Model calculations of subsurface transport of mofetta gases and radon revealed the influencing effects of weather conditions on seepage velocity and ^{222}Rn activity concentration in soil.

A10

AIR CONDITIONING IMPACT ON THE DYNAMICS OF EFFECTIVE DOSE DUE TO RADON AND ITS SHORT-LIVED DECAY PRODUCTS

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Measurements of radon and its progeny in attached and unattached fractions makes it possible to determine effective inhalation dose.

The paper presents the results of two series of measurements carried out in the auditorium of Environmental Engineering Faculty (Lublin University of Technology, Poland). The study encompassed the measurements of radon and its progeny (in attached and unattached fractions) as well as indoor air parameters: temperature, relative humidity, air pressure, number and mass concentrations of fine aerosol particles. The measurements were carried out during several periods of time: with air-conditioning switched off all the time, switched on and with its typical use: switched on during the day and off in the night. Moreover, some additional parameters of the air-conditioning work were taken into account: stream flow, air recirculation. The separation of radon progeny into attached and unattached fractions allow to determine dose conversion factor (DCF) and, respectively, to determine inhalation dose for lecturers and students in the auditorium. It was observed that air-conditioning influence significantly the dynamics of radon and its progeny concentration and hence levels of effective inhalation dose.

The significant increase of the mean radon progeny concentration (in both fractions) from 1.2 Bq/m^3 to 5.0 Bq/m^3 occurred when air conditioning was working during a day and switched off during night. This also resulted in increasing inhalation dose from 0.005 mSv/y to 0.016 mSv/y (assuming residence time in auditorium at the level of 200 hours per year). Furthermore changing amount of recirculated air caused a decrease of the mean radon concentration from 30 Bq/m^3 to 12 Bq/m^3 and reducing the mean radon progeny concentration from 1.4 Bq/m^3 to 0.8 Bq/m^3. This resulted in the reduction of inhalation dose from 0.006 mSv/y to 0.003 mSv/y.

Acknowledgements:

Work performed within the research project "The influence of indoor air parameters on the dynamics of radon and its progeny concentrations", financed by National Science Centre, contract No. 7454/B/TO2/2011/40.

A11

CONTRIBUTION OF RADON PROGENY TO THE EXTERNAL GAMMA DOSE: THE EXPERIENCE AT LNR

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The new Basic Safety Standards (BSS) for protection against the dangers arising from exposure to ionising radiation came into force in January 2014 [1]. This document introduces radon gas into the system of radiological protection for the first time. The Directive maintains the current annual effective dose limits for occupational and public exposure situations. For the case of workplaces, radon is considered to be an existing exposure situation when it enters from the ground into the building. Such radon exposures can be significant and not negligible.

It is a common practice to avoid considering the contribution of radon daughters to the external gamma dose. There are several publications where there is no evidence of correlation between these two parameters. However, in most of them radon concentrations are relatively low (less than 1000 Bq m^{-3}). It is possible to find in the literature works which undertake the contribution of radon gas to the gamma dose, but they are based on numerical calculations only.

We present a study aiming to determine the contribution of radon to the external dose performed at the Laboratory of Natural Radiation (Ciudad Rodrigo, Spain). This building has radon concentrations and external gamma radiation subjected to daily variations due to changes in environmental conditions [2]. In our work, we analyse more than 5000 data obtained during one year of monitoring both parameters. The maximum radon concentration was 205 kBq m^{-3} (median 22 kBq m^{-3}) and 1.5 μ Gy h^{-1} for the absorbed dose rate (median 0.3 μ Gy h^{-1}). We also include the time series data of meteorological parameters to complete the study together with particle distribution in the building.

Our main findings reveal that there is an excellent linear correlation between radon concentration indoors and absorbed gamma dose rate in the same room. In addition, we performed analysis of this relation considering different bins of radon concentrations, especially paying attention to the reference level of 300 Bq m^{-3} [1]. To sum up, our results reveal that contribution of radon to the external gamma dose rate must be considered significant for those cases where exposures are higher than 1000 Bq m^{-3}.

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[2] J.L. Gutierrez-Villanueva, C. Sainz, I. Fuente, J.C. Sáez-Vergara, E. Correa, L.S. Quindos Poncela: Intercomparison exercise on external gamma dose rate under field conditions at the laboratory of natural radiation (Saelices el Chico, Spain). Radiation protection Dosimetry 155 (2013) 4, pp.459-466.

A12

COMPARATIVE ANALYSIS OF RADON CONCENTRATIONS DERIVED FROM SEPARATE INDOOR RADON SURVEYS CONDUCTED IN DWELLING AND SCHOOL SITES IN KUWAIT

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Comparative analysis of two radon concentration surveys carried out in different parts of Kuwait was conducted; one survey was carried out in different locations within dwellings, and the other was carried out in classrooms of secondary schools. Both studies involved short-term radon measurements. Packard Pico-Rad vials containing small amounts of activated charcoal were exposed for two days in different dwellings (living rooms, bedrooms, basements) and then analyzed with liquid scintillation counting, while the active radon monitor “AlphaGUARD” was used to measure radon in the classrooms by keeping it in each location (classroom) for two days to provide the average readings of 48 hour sampling measurements.

For expanded comparison, other data are also included that were obtained from measurements performed for indoor radon concentrations in elementary schools in Kuwait as well as in Tunis, the capital of Tunisia. The measurements in Tunis were carried out in schools building which are more than 100 years old, and these measurements were long-term measurements with nuclear track detectors.

Despite the difference of geographical locations, site locations, building structures, seasons and level of occupation, the average radon concentration levels were found to be less than the ICRP (1993) recommended action level of 200–600 Bq/m3 and within limits of countries with similar climate conditions.

Keywords: Radon, School Buildings, Kuwait schools, dwelling

A13

THE CHARACTERITICS OF ^{222}Rn/^{220}Rn CONCENTRATION FROM SOIL GAS IN SHENZHEN CITY (SOUTHERN PART OF CHINA)

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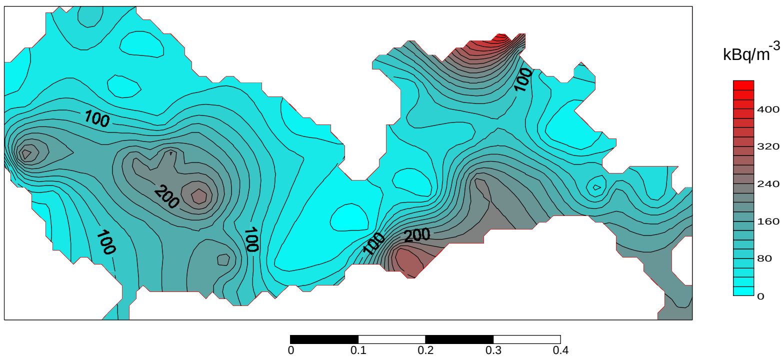
Shenzhen City (SC), located in the southern part of china and bordered with Hongkong, is a city with high radiation background, where mainly covered with the Middle and Late Jurassic and the Cretaceous biotitic-granite. The mean gamma air absorbed dose rates is 82.1±33.0 nGyh^{-1} and the range is from 1.9 nGyh^{-1} to 368 nGyh^{-1} in SC, estimated from uranium-238, thorium-232 and potassium-40 radioactivity concentration by the airborne gamma-ray spectrometry. So a preliminary investigation of ^{222}Rn/^{220}Rn concentration in soil gas in SC was conducted using a portable semiconductor radon monitor RAD7 for understanding ^{222}Rn/^{220}Rn level and distribution in different types of rocks and soils in 2013 in Guangdong Province of China.

The characteristics and distributions of ^{222}Rn/^{220}Rn from soil gas are obviously related with geological lithology in SC. ^{222}Rn concentrations vary from 39.8 to 369.7 kBqm^{-3} and from 14.6 to 118.3 kBqm^{-3} in weathered granite products and sediments or lava, respectively, while ^{220}Rn concentrations are from 102.8 to 435.0 kBqm^{-3} and 2.22 to 95.8 kBqm^{-3}. The ^{222}Rn and ^{220}Rn average values of the total 69 samples are 86.0±72.1 kBqm^{-3} and 117.7±85.0 kBqm^{-3}, respectively. The contour map of ^{220}Rn concentration in soil gas in SC is shown as in Figure 1. The sites with high ^{220}Rn value measured are mainly located in the areas hosted by the weathered granite products. Comparison with the distribution of ^{222}Rn concentration, the areas of high ^{220}Rn values are larger. ^{220}Rn concentrations have no statistically significant variations from depths of 20 to 160 cm with an interval of 20 cm, but ^{222}Rn concentrations increase as the depths increase in the sites of Wutongshan Mountain and Laiwushan Mountain.

Our preliminary radon investigations show that: (1) the characteristics and distributions of ^{222}Rn/^{220}Rn concentration from soil gas in SC are obviously related with local lithology and geological formation. High ^{222}Rn/^{220}Rn concentrations were observed in soil gas in the outcrops of weathered granite or filled back granite sands. (2) The distribution model of ^{222}Rn is near as same as that of ^{220}Rn. (3) ^{220}Rn concentrations have no statistically significant variation as depth, but ^{222}Rn concentration increases as sampling depth increases.



The investigation suggests that we should pay attention to ^{220}Rn contribution in radon mapping in SC, as well as in indoor radon survey and dose assessment.

The research was supported by National Natural Science Foundation of China (No. 41474107, No.41274133 and 41074096).

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A14

DEVELOPMENT OF AN ELECTRONIC MONITOR FOR THE DETERMINATION OF INDIVIDUAL RADON AND THORON EXPOSURE

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The carcinogenic effect of the radio isotope Rn-222 of the noble gas radon and its progeny, as well as its residential distribution, are well studied [1]. In contrast, the knowledge about the effects and average dwelling concentration levels of its radio isotope Rn-220 ("thoron"') is still limited [2]. Generally, this isotope has been assumed to be a negligible contributor to the effective annual dose. However, only recently it has been pointed out in several international studies [3]–[6], that the dose due to thoron exceeds the one from Rn-222 under certain conditions. Additionally, radon monitors may show a considerable sensitivity towards thoron which was also not accounted for in general [7], [8]. Therefore a reliable, inexpensive exposimeter, which allows distinguishing between decays of either radon and thoron, is required to conduct further studies.

Recently an electronic radon/thoron exposimeter which features small size, low weight and minimal power consumption was developed at the Helmholtz Center Munich (HMGU) [9]. The design is based on the diffusion chamber principle and employs state-of-the-art alpha particle spectroscopy to measure activity concentrations. The device was optimized via inlet layout and filter selection for high thoron diffusion. Calibration measurements showed a similar sensitivity of the monitor towards radon and thoron, with a calibration factor of $cf_{Rn\text{-}222}$ =16.2 ± 0.9 Bq×m^{-3}/cph and $cf_{Rn\text{-}220}$=14.4±0.8 Bq×m^{-3}/cph, respectively. Thus, the radon sensitivity of the device was enhanced by a factor two compared to a previous prototype [10]. The evaluation method developed in this work, in accordance with ISO 11665 standards [11], was validated by intercomparison measurements. The detection limits for radon and thoron were determined to be $C^{\#}_{Rn\text{-}222}$=44.0 Bq×m^{-3} and $C^{\#}_{Rn\text{-}220}$=40.0 Bq×m^{-3}, respectively, in case of a low radon environment, a one-hour measurement interval, and a background count rate of zero. In contrast, in mixed radon/thoron concentrations where the Po-212 peak must be used for thoron concentration determination, a calibration factor of $cf_{Rn\text{-}220}$=100±10~8 Bq×m^{-3}/cph was measured, yielding a detection limit of $C^{\#}_{Rn\text{-}220}$=280.0 Bq×m^{-3}.

Further, Monte Carlo (MC) simulations were performed by means of various codes including Geant4, to study the effect of the variation of parameters influencing the calibration factors. The results showed reasonable agreement between simulated and acquired spectra, with differences being below 8%, thus validating the employed simulation model. The simulations indicated a significant impact of environmental parameters, such as temperature and pressure, on the measured spectra and accordingly on the calibration factor. Therefore the calibration factor was quantified as a function of temperature, relative humidity and pressure as well as chamber volume. For devices with increased detection volume a considerable influence of air density changes, corresponding to altitudes from 0-5000 m, and temperatures from -25 to 35 °C, on the calibration factor of up to 32% was observed. In contrast, for devices with standard housing the calibration factor changed only up to 4%.

This indicates that Monte-Carlo simulations are a valuable tool to predict the sensitivity of exposimeters and their dependence on influencing parameters.

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A15

PoCAMon - PERSONAL ONLINE CONTINUOUSE AIRMONITOR NOT ONLY FOR RADON AND THORON DECAY PRODUCTS

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The PoCAMon combines a very compact design with a high flow rate and long battery life. Its size and weight are still acceptable for carrying by one person.

The unit measures long-lived aerosols as well as short-lived Radon/Thoron daughters by alpha spectroscopy and beta counting. The radioactive aerosols and particles are collected on the surface of a high resolution membrane filter. The alpha and beta decays on the filter are measured by a high-end semiconductor radiation detector (400 mm²). This allows a perfect separation of the different decay products.

The increased pump rate (more than 3 l/ min) is suitable for lower detection limits. The low noise rotary van pump is processor controlled and guarantees a constant flow rate over the hole measuring time. A sensor measures permanently the pressure drop on the filter in order to recognize an exhausted or perforated filter instantly.

With the 3.8 Ah NiMH battery pack the PoCAMon achieves an operation time of more than 30 hours.

The quality control is a main issue of any radiation measurement. Therefore the PoCAMon records a complete alpha spectrum for each measured value. This allows the monitoring of the device's perfect operation in each moment of the measurement.

There are options for additional sensors for carbon monoxide and combustible gases as needed in underground mines.

All measured data are stored in a 2GB memory card and can be accessed with a PC or laptop via a USB interface. Data transmission and device control can also be done via wireless ZigBee network or via a server for stationary operation with network access. A barometric pressure sensor and a GPS receiver are optional features of the device.

A16

TECHNICAL PROCEDURE TO DETERMINE THORON INDOOR CONCENTRATION BY LR-115 TYPE II

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Thoron (Tn), an invisible, odorless, heaviest (nine times heavier than air) and radioactive gas is an aberration. The purpose of this project is to measure separately Rn-222 and Rn-220 (thoron). We have used two types of chamber: urban-cup and 3x3 box with LR-115, Type- II (Kodak Pathe, France) detector. We have investigated how LR-115 work for Tn by using Monazite ore to simultaneously measure Rn-222 and Rn-220. To carry out experiment we are using urban-cup, 3x3 box with and without PE membrane. Urban cup and 3x3 box with PE membrane only detect Rn-222, whereas without PE membrane they detect total Rn-222 and Rn-220. The precision was evaluated by duplicate measurement at 8 cm detector-source distance with standard deviation less than 2.54%. In order to test technical procedure, we have sent detectors to NIRS, Japan for calibration exposure. After the detectors have been exposed at NIRS, we carry out following all steps of procedure which is set up at laboratory in INST, Vietnam. Finally, we calculated calibration factor which is 0.21 [tracks.cm^{-2}/Bq.m^{-3}.h] and we constructed the curve between integrated Rn-220 concentration and track density with factor R^2 = 0.975.

A17

UPGRADE OF THE UNATTENDED BATTERY- OPERATED THORON PROGENY MEASUREMENT DEVICE

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An Unattended Battery-Operated Thoron Progeny Measurement Device (UBPM) was introduced for thoron (Rn-220) progeny measurement in inhabited dwellings [1]. It is a kind of passive detector which uses high voltage electric field to precipitate negatively charged and neutral radon and thoron progenies on sampling substrates. As sampling substrates, aluminium foil covered solid-state nuclear track detectors (CR-39) are used. It is used for the assessment of thoron progeny concentration in inhabited dwellings. However, the influence of radon on the thoron progeny result, which was necessary for measurements in mixed radon and thoron atmosphere, was unknown. In addition, the same principle of operation should be applicable for the direct measurement of radon decay products.

This study upgraded the device by using aluminium foils of two thicknesses to discriminate 7.69 MeV and 8.78 MeV alpha particles emitted respectively by radon progeny Po-214 and thoron progeny Po-212, in order to measure radon and thoron progeny concentrations simultaneously.

Efficiencies were calibrated and applicability of the device in various environmental conditions was tested during the calibration.

Experiment results showed the efficiencies of radon and thoron progeny on the substrate covered by thicker aluminium foil are 0.52 tracks/(Bq/m^3×d) and 13.5 tracks/(Bq/m^3×d) respectively. Po-214 will contribute more than 10% of the tracks on that area, when the device is used in mixed radon and thoron atmosphere. According to the environmental applicability test, this device can operate with repetitious accuracy in ordinary conditions (humidity<70%, unattached fraction<6%).

The updated UBPM device, which is silent, power supply independent, and can evaluate concentrations of both radon and thoron progeny simultaneously, is suitable for long period dose assessment in inhabited dwellings for both radon isotopes.

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A18

RADON AND THE LUNG CANCER – A REAL EFFECT OR JUST AN ASSUMPTION?

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The subject of the potential lung cancer and radon concentration is present in the scientific literature for years. To check whether this correlation is real or if it is just an assumption, the influence of the ^{222}Rn ionizing radiation on the lung cancer risk examined in 28 papers was re-analyzed using seven alternative dose-response models. The risks of incidence and mortality were studied in two ranges of low annual equivalent radiation dose: 0–70 mSv per year (391 Bq m^{-3}) and 0–150 mSv per year (838 Bq m^{-3}). The assumption-free Bayesian statistical methods were used. The analytical results demonstrate that the published incidence and mortality data do not lead to the conclusion that radiation dose is associated with increased risk in this range of the doses. This statement is based on the fact that the model assuming no dependence of the lung cancer induction on the radiation doses is at least circa 90 times more likely to be true than the other models tested, including the linear no-threshold (LNT) model.

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A19

LUNG CANCER MORTALITY AND RADON EXPOSURE IN RUSSIA

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More than 400,000 measurements of indoor radon equivalent equilibrium concentration (ECC) were performed by regional departments of Rospotrebnadzor (government body, in particular, responsible for radiation protection) since 2008. The data for 83 regions of Russia are summarized in annual reports issued by Saint-Petersburg Ramzaev Research Institute of Radiation Hygiene. By the same manner Moscow Hertzen Cancer Research Institute collects and summarize the data on oncological morbidity and mortality in Russia. We compare the data of these databases in order to investigate the association between the lung cancer and indoor radon exposure in Russian population. Average radon ECC for each region was estimated using the annual reports for the period 2008-2013. Average standardized lung cancer mortalities among males and females were estimated as well using the reports for the period 2008-2012. To study the relationship between exposure and mortality, obtained information was divided into seven exposure intervals. Relative risk (RR) was estimated as ratio between average mortality within each exposure interval and background mortality. Dependences between RR of lung cancer and radon ECC for females and males are presented on Figure 1.

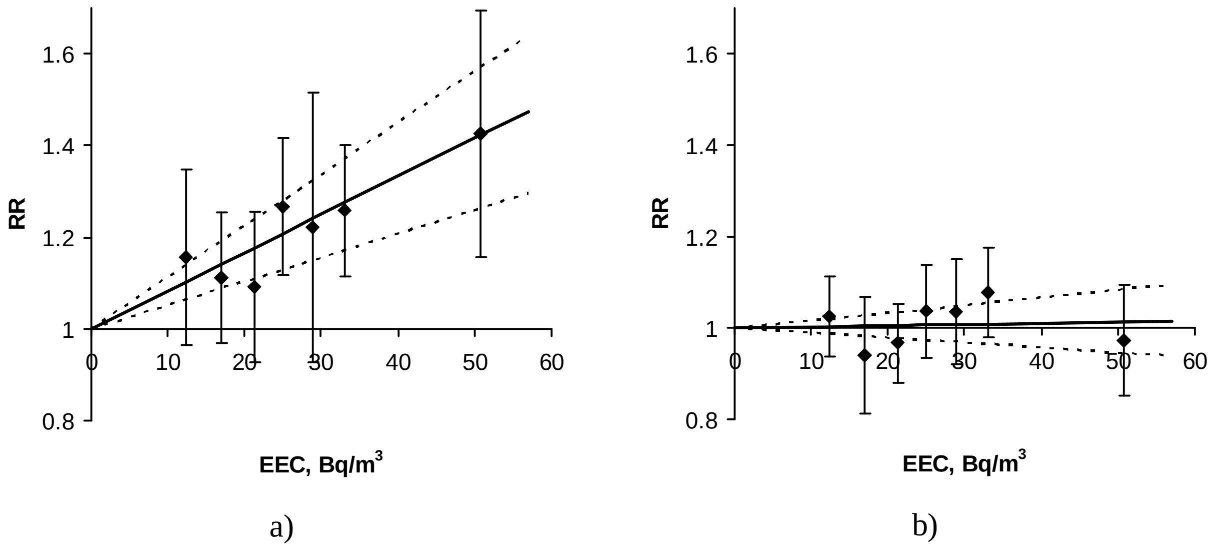

Figure 1. Dependence between RR of lung cancer and radon ECC for females (a) and males (b). points – RR, whiskers – 90% CI, solid line – linear dependence, dash line – 90% CI of linear dependence.

Slope factor of linear dependence between indoor radon exposure and lung cancer RR are 0.026 (-0.11–0.17) and 0.83 (0.52–1.12) per 100 Bq/m^3 of radon EEC for males and females respectively (with 90% CI). Obtained results can be explained by confounding effect of the tobacco smoking. Significant excess risk of lung cancer in female population can be associated with radon exposure and low prevalence of smoking.

A20

RADIATION DOSES TO DOCTORS, NURSES AND PATIENTS DUE TO RADON SHORT-LIVED PROGENY FROM THE INHALATION OF AIR IN URBAN HEALTH CENTRES

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Alpha-and beta-activities per unit volume of air due to radon (^{222}Rn), thoron (^{220}Rn) and their decay products were measured in the air of various health centres situated in different districts of the city of Marrakech. Both CR-39 and LR-115 type II solid state nuclear track detectors (SSNTDs) were used. The committed equivalent doses due to the ^{218}Po and ^{214}Po radon short-lived progeny were evaluated in different tissues of the respiratory tract of doctors, nurses and patients from the inhalation of air inside the studied health centres. Annual effective doses due to radon progeny from the inhalation of air by doctors, nurses and patients inside the studied health centres were evaluated.

A21

NEW FINDINGS ON THE HETEROGENEOUS DOSE RESPONSE CURVE FOR RADON AND LUNG CANCER

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According to the report published by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in 2000, Ramsar city in northern Iran, has some inhabited areas with the highest known natural background radiation levels in the world [1]. Indoor radon concentration in some regions of high background radiation areas (HBRAs) of Ramsar are up to 31 kBq m^{-3}[2], a concentration that is much higher than the action level recommended by the U.S. Environmental Protection Agency (EPA) (148 Bq m^{-3} or 4 pCi/L). Considering high levels of public exposures to ionizing radiation in the residents of HBRAs of Ramsar, some experts have recently suggested that an effective remedial action program is needed [2]. The 1st report on the induction of adaptive response in the residents of HBRAs was published by our group [3]. We have also previously shown that the highest lung cancer mortality rate in HBRAs of Ramsar was in a district with normal levels of radon while the lowest lung cancer mortality rate was in another district with the highest concentrations of radon in the dwellings [4]. To further investigate the shape of the dose-response curve for lung cancer in HBRAs of Ramsar, we performed a new study in 2014. No excess cancer risk from exposure to terrestrial gamma radiation was found for cancers other than lung. Interestingly, in this new study, there is evidence that lung cancer risk is relatively higher in HBRAs due to higher levels of radon. On the other hand, no increase in overall cancer incidence was found in the residents of HBRAs with regard to radiation levels. We believe that to some extent, this heterogeneous dose response relationship, may be due to the the small population size [5-6] that limits the statistical power and the role of the risk factors such as smoking and diet.

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A22

SIMULTANEOUS MEASUREMENTS OF RADON AND THORON DECAY PRODUCTS IN AIR

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Liquid scintillation counting (LSC) is a measuring technique, broadly applied in environmental monitoring of radionuclides. One of the possible applications of LSC is the measurement of radon and thoron decay products. But this method is suitable only for grab sampling.

For long term measurements a different technique can be applied – monitors of potential alpha energy concentration (PAEC) with thermo luminescent detectors (TLD). In these devices, called ALFA-2000 sampling probe, TL detectors ($CaSO_4$:Dy) are applied for alpha particles counting. Three independent heads are placed over the membrane filter in a dust sampler's microcyclone. Such solution enables simultaneous measurements of PAEC and dust content. Moreover, the information which is stored in TLD chips is the energy of alpha particles, not the number of counted particles. Therefore the readout of TL detector shows directly potential alpha energy, with no dependence on equilibrium factor etc. This technique, which had been used only for radon decay products measurements, was modified by author to allow simultaneous measurements of radon and thoron PAEC.

The LSC method can be used for calibration of portable radon decay products monitors. The LSC method has the advantage to be an absolute one, the TLD method to measure directly the (dose relevant) deposited energy.

A23

ANALYSIS OF SIMULTANEOUS TIME SERIES OF INDOOR AND OUTDOOR RADON CONCENTRATIONS, METEOROLOGICAL AND SEISMIC DATA

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It is well known that the temporal evolution of indoor and outdoor radon concentrations show complex patterns, which are partly not easy to interpret. Clearly, for physical reasons, they must be related to possibly variable conditions of radon generation, migration and atmospheric dispersion and accumulation. The aim of this study was to analyse long time series of simultaneously measured indoor and outdoor radon concentrations, together with environmental quantities which may act as control variables of Rn. These are wind speed and direction, precipitation, temperature, dew point, pressure, relative humidity as well as earthquake magnitude. It was examined whether, or to which degree, the periodic (diurnal and seasonal) and non-periodic fluctuations of radon can be related to the ones of the environmental factors.

The study was performed in Chiba, Japan, using two AlphaGUARDs ionization chambers for parallel indoor and outdoor radon concentrations measurements over 4 years. The metrological and seismic data were obtained from the Japan Metrological Agency.

A24

RADON EMISSION RATE AND ANALYSIS OF ITS INFLUENCING PARAMETERS

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The radon emission rate describes the radon characteristics of a building which are defined by structural (tightness of the building envelope) and geological (concentration of radon emitting from the ground) conditions. Therefore, all sources of radon emission into a building are considered, in particular the radon emitted from the ground.

For the determination of radon emission-rate the concentration-decay method according to the VDI guideline 4300-7 (Measurement of the indoor air change rate) and measurement of radon are used.

The procedure of the VDI guideline demands that a tracer gas is injected into the room which will be analyzed. The air change rate will be calculated from the decay of the concentration of the tracer gas over the time. Combined with the recorded data of the radon (in the same room and outdoors) it is possible to calculate the radon emission rate.

Additionally, meteorological parameters like temperature, atmospheric pressure, humidity, precipitation rate, wind speed, and wind direction are recorded and their possible impact on the radon emission rate is analyzed.

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A25

NUMERICAL MODELLING OF RADON TRANSPORT FROM SOIL TO A HOUSE BASEMENT UNDER VARIABLE WEATHER CONDITIONS

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In France, radon exposure is the first source of ionizing radiation. To improve evaluations of human exposure, it is necessary to enhance the knowledge on radon transfer from its source (anthropic or natural) to enclosed spaces (dwellings, workplaces, public buildings) or to the environment.

Numerical modelling is necessary to better understand transient phenomena of radon transport from an unsaturated soil to a house basement where high radon levels can be observed. However, only few modelling studies have been conducted in the past to simulate these phenomena under highly fluctuating weather conditions (rainfall, evaporation, atmospheric air pressure and temperature…). These studies were focused on the modelling of indoor air depression and most of them did not account for instantaneous soil moisture variations under dry (evaporation) and wet (rainfall) conditions around the soil/basement interface.

The present work aims to develop a robust and simplified two-dimensional (2D) numerical simulation model by accounting for such variations. The developed model uses the approach of equivalent continuum porous medium (ECM) for modelling radon transport through the cracks at the soil/basement interface. Therefore, effective porosity and permeability have been used in our modelling approach to represent the cracked concrete in the walls blocks and in the slab. This modelling approach has been applied for simulating radon transport into a house basement, considering the presence of an aquifer with a given water-table depth, the effects of rainfall, evaporation, atmospheric air pressure, and house-depression due to human occupation.

Sensitivity analysis of the model parameters (crack thickness, vacuum pressure in basement, soil permeability, water table depth…) has been performed in order to determine the impact of their variations on the radon activity concentration within the indoor air.

A26

TEMPORAL VARIABILITY OF NEAR-GROUND ATMOSPHERIC RADON OVER CENTRAL EUROPE

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Concentration of radon (^{222}Rn) in the near-ground atmosphere has been measured quasi-continuously from January 2005 to December 2009 at two continental sites in Europe: Heidelberg (south-west Germany) and Krakow (southern Poland). Both stations were equipped with identical radon monitors. The instruments were developed at the Institute of Environmental Physics, University of Heidelberg, Germany [1]. The instruments measure specific activity of ^{222}Rn in air through its daughter products. Regular observations of ^{222}Rn were supplemented by measurements of surface fluxes of this gas in the Krakow urban area, using two different approaches: (i) night-time ^{222}Rn fluxes were derived from measurements of atmospheric ^{222}Rn content near the ground, combined with quasi-continuous measurements of the mixing layer height within the planetary boundary layer (PBL) and modelling of vertical ^{222}Rn profiles in the atmosphere using a regional transport model, and (ii) point measurements of soil ^{222}Rn fluxes were performed using a specially designed exhalation chamber system connected to an AlphaGUARD radon detector.

The measured concentrations of ^{222}Rn varied at both sites in a wide range, from less than 2.0 Bqm^{-3} to approximately 40 Bqm^{-3} in Krakow and 35 Bqm^{-3} in Heidelberg. The mean ^{222}Rn content in Krakow, when averaged over the entire observation period, was 30% higher than in Heidelberg (5.86±0.09 and 4.50±0.07 Bqm^{-3}, respectively). Distinct seasonality of ^{222}Rn signal is visible in the obtained time series of ^{222}Rn concentration, with higher values recorded generally during late summer and autumn. The surface ^{222}Rn fluxes measured in Krakow also revealed a distinct seasonality, with broad maximum observed during summer and early autumn and minimum during the winter. The mean ^{222}Rn flux derived from chamber measurements (50.3 ± 8.4 Bqm^{-2} h^{-1}) agrees very well with the sodar-assisted estimate of this flux (50.3 ± 3.4 Bqm^{-2} h^{-1}). Systematic observations of ^{222}Rn atmospheric concentration, supplemented by measurements of surface ^{222}Rn fluxes, allowed a deeper insight into factors controlling spatial and temporal variability of ^{222}Rn over central Europe.

[1] Levin, I., Born, M., Cuntz, M., Langendörfer, U., Mantsch, S., Naegler, T., Schmidt, M., Varlagin, A., Verclas, S., and Vagenbach, D.: Observations of atmospheric variability and soil exhalation rate of radon-222 at a Russian forest site, Tellus B, 54(2002), pp.462–475.

A27

THE SUITABILITY OF AMBIENT GAMMA DOSE RATE AS PREDICTOR OF THE GEOGENIC RADON POTENTIAL

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Estimating radon prone areas is an important part of radon action plans. In whichever way these areas and the Rn potential as underlying concept are defined, this requires considerable efforts of sampling indoor or soil radon. When spatial coverage or sampling density of such data are insufficient, one would like to be able to estimate such areas at least roughly or in an indicative manner through proxy quantities which are more readily available. One candidate quantity is ambient gamma dose rate whose terrestrial component is partly generated by radionuclides of the ^{238}U series, to which also ^{222}Rn belongs. Ambient dose rate is easy to survey; in Europe, it is available through the constant operation of national radiation early warning networks, together forming the EURDEP network.

We investigate the suitability of dose rate as predictor of the radon potential or Rn prone areas, using five examples (in alphabetical order): (1) Readings of the *Austrian* Early Warning Network and the "Friedmann" Rn potential; (2) Readings of the *Belgian* Early Warning Network and the radon potential according Belgian definition; (3) Results of a recent regional survey in *Brazil*, consisting of a car-borne dose rate and a residential indoor Rn survey [1]; (4) Readings of the *German* Early Warning Network and measurements of the "Neznal" geogenic Rn potential; and (5) the *Spanish* MARNA survey of ambient dose rate and the Spanish indoor Rn survey [2].

We review existing results, present the data and analysis methods, as well as first results from newly available data. A number of sources of uncertainty in estimation of the terrestrial dose rate component is also addressed

[1] Projeto Planalto (2009 and 2013): Projeto Planalto Poços de Caldas - Pesquisa Câncer e Radiação Natural, Minas Gerais, Brasil 2004 a 2013; vol I & II.; Ed. Governo de Minas / Secretaria de Estado de Saúde.

[2] García-Talavera M., García-Pérez A., Rey C. and Ramos L. (2013): Mapping radon-prone areas using γ-radiation dose rate and geological information. J. Radiol. Prot. 33, 605 – 620.

A28

MAPPING RADON AND DEFINING RADON PRONE AREAS: EVALUATION OF POSSIBLE METHODS FOR AUSTRIA

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Identifying and defining "radon prone areas" is mandatory for all EU member states according to the new EU BSS [1]. Therefore this subject is currently of interest and discussed by experts in and among the European countries, also in Austria. A workshop on this topic was hosted in Vienna in January 2015 with radon mapping experts from 7 countries to present and discuss methods and strategies.

The current radon map of Austria is based on about 20,000 indoor measurements normalized for a standard situation (radon potential) [2]. At the moment, measurement campaigns are ongoing to increase the indoor radon data, with measurement points selected based on a regular 2x2 km grid, taking geology into account. As these measurements will take several years and radon classification of administrative units will still be afflicted with high uncertainties, this radon mapping activity alone is not sufficient and satisfactory for the implementation of the EU BSS in Austria.

As an outcome of the radon mapping workshop, some ideas for mapping methods and definitions of radon prone areas (as discussed and presented by the experts) are evaluated for their suitability for Austria. Together with indoor radon, additional data should be included to characterize areas regarding radon. The availability of such data and the possibility to use them as input parameters to classify radon areas (e.g. aero-radiometry, geological information, soil permeability etc.) is assessed in co-operation with the Austrian Geological Survey and the EC JRC.

In this contribution some radon mapping methods and definitions of radon prone areas will be evaluated and discussed for Austria, with respect to experiences in other European countries.

[1] Council of the European Union (EU): Council directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing directives 89/618/Euratom, 96/29/Euratom and 2003/122/Euratom. Official Journal of the European Union, L 13, Volume 57, p. 1–73, 17 January (2014)

[2] Friedmann, H.: Final Results of the Austrian radon project. Health Physics, Vol. 89 (4), pp. 339-348 (2005)

A29

MAPPING OF INDOOR RADON AND TERRESTRIAL GAMMA RADIATION LEVELS IN FRANCE: GEOSTATISTICAL MODELING

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In France, natural sources account for most of the population exposure to ionising radiation. Previous studies realized in France by the Institute for Radiological Protection and Nuclear Safety (IRSN) provided maps of arithmetic means of indoor radon concentrations and terrestrial gamma dose rates by district based on measurement results. However, numerous areas were not characterized due to the lack of data. The aim of our work was to obtain more precise estimates of the spatial variability of indoor radon concentration (IRC) on the one hand and indoor terrestrial gamma dose rate (ITGR) on the other hand, by using a more recent and enriched data base and geostatistical modeling.

The study was initially based on measurement results distributed in 17,404 locations for gamma rays and 10,843 locations for radon, covering the whole French territory. Radon data came from a national radon survey beginning in the eighties which was conducted in French dwellings by the IRSN and the French Health Ministry (DGS). ITGR measurements were realized by the IRSN in 2011 and 2012, in French dentist surgeries and veterinary clinics; the results used came from dosimeters which were not exposed to anthropic sources. The ITGR varied between 13 and 349 nSv/h, with an arithmetic mean of 76 nSv/h. The IRC varied between 5 and 4,382 Bq.m^{-3} with an arithmetic mean of 89 Bq.m^{-3}.

Firstly, ordinary kriging was performed in order to estimate averaged values on cells of 1x1 km² all over the domain. The second step of the study was to use an auxiliary variable in estimates. Actually, the IRSN achieved in 2010 a mapping of the geological uranium potential (GUP) and the geogenic radon potential (GRP), each classified in 5 categories, of the French geological formations, at the scale 1:1 000 000. The GUP and the GRP, which are exhaustive along the French territory, were used to help in estimating respectively ITGR and IRC. Such approach was possible using multilinear geostatistics and cokriging. Cokriging was performed on 1x1 km² cells all over the domain. The geostatistical models used i) ITGR measurement results and GUP classes and ii) IRC measurement results and GRP classes.

We present and discuss here the maps of ITGR and IRC obtained by different geostatistical models mentioned above. The present work provides more precise indicators on the spatial variability of the French population exposure to natural radioactivity. It provides useful information for mapping radon-prone areas, for the evaluation of the natural radiation background or for epidemiological studies and risk assessment from low dose chronic exposures.

A30

ESTIMATION OF THE GEOGENIC RADON POTENTIAL USING URANIUM CONCENTRATION IN BEDROCK AND SOIL PERMEABILITY DATA, INTEGRATED WITH GEOLOGICAL INFORMATION

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Areas where the radon concentration in a significant number of buildings is expected to exceed the relevant national reference level shall be identified by Member States, as requested by the new European Directive on Basic Safety Standards [1]. This could be done using direct measurements of indoor radon or indirect quantities, such as soil gas radon and soil permeability, terrestrial gamma dose, geochemical data and geological information. In general these quantities are related to the concept of the geogenic radon potential [2].

We present a study to estimate the geogenic radon potential, hence to identify radon-prone areas, using as input quantities Uranium (U) concentration in bedrock and soil permeability data, integrated with geological information.

The methodological approach consists of the following activities:

a) Identify, using OneGeology-Europe data, geological units homogenous in U content using lithostratigraphy, petrology and mineralogy knowledge;
b) Assign U concentration in bedrock value to each geological unit using data from scientific literature;
c) Estimate the radon potential combining U concentration in bedrock and soil permeability data;
d) Check the goodness of the method using indoor radon data.

In a first step we apply the method in Austria; data and results are reported.

At the European level the present work represents a preliminary study for the development of some maps planned for the European Atlas of Natural Radiation, which is being developed by the Radioactivity Environmental Monitoring (REM) group of the Joint Research Centre (JRC) of the European Commission. In fact the Atlas should display a map of U concentration in bedrock and geogenic radon maps based on several variables, among which the U concentration in bedrock and soil permeability.

[1] EC (European Commission), 2013. Council Directive 2013/59/Euratom of 5 December 2013 laying down Basic Safety Standards for Protection against the Dangers Arising from Exposure to Ionising Radiation. Available on http://eur-lex.europa.eu/JOHtml.do?uri=OJ:L:2014:013:SOM:EN:HTML

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A31

QA/QC OF RADON MEASUREMENTS IN ACCREDITED LABORATORIES

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Laboratory for Radioactivity and Dose Measurements at the Faculty of Sciences in Novi Sad has a long tradition in radon measurement with several different methods. As an accredited laboratory it has quality control procedures for monitoring the validity of measurements undertaken in order to meet the requirements specified in ISO/IEC 17025:2006 International Standard. These procedures include replicated tests using the same or different methods, internal QA/QC using certified reference materials, participation in interlaboratory comparison or proficiency-testing programmes and intermediate checks of calibrated equipment. The results of this monitoring for radon measurements performed in our laboratory are presented and analyzed in the paper and might have multiple benefit for other laboratories involved in the process of accreditation as well as to achieve higher precision of radon measurements.

A32

RADON RESEARCH IN POLAND: A REVIEW

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The article presents the most important results of radon research in Poland. Large-scale research, launched in this country in the early 1950s, was originally linked to using radon dissolved in groundwaters in balneotherapy as well as to uranium ore exploration and mining. This early research focused on the area of the Sudetes and nowadays it is also south-western Poland where most radon research is being conducted. This is chiefly due to the geological structure of the Sudetes and the Fore-Sudetic block, which is propitious to radon accumulation in many environments. Radon research in Poland has been developing dynamically since the 1990s. A lot of research teams and centres have been formed, all of them using a variety of methods and advanced measurement equipment enabling research into radon occurrence in all geospheres and all spheres of human activity. The author presents the contribution of Polish science to broadening human knowledge of the geochemistry of radon, particularly of ^{222}Rn isotope. The article also presents the ranges and mean values of ^{222}Rn activity concentration measured in different environments in Poland including the atmospheric air, the air in buildings and underground hard-coal and copper mines, cave air, the air in underground tourist sites and abandoned uranium mines as well as soil air and groundwaters.

A33

RESULTS OF THE 2015 NATIONAL INDOOR RADON INTERCOMPARISON MEASUREMENTS

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Results and conclusions of indoor radon interlaboratory comparison in 2015 in Serbia are presented. The participants were three accredited laboratories from Serbia: Serbian Institute of Occupational Health "Dr Dragomir Karajović", Laboratory for Radioactivity and Dose Measurements at the Faculty of Sciences, University of Novi Sad and Radiation and Environmental Protection Department, Vinča Institute of Nuclear Science. The laboratories are practicing the same method for radon measurement using charcoal canisters according to US EPA protocol 520/5-87-005 [1]. Radon is adsorbed onto the charcoal grains and decays to radon short-lived progenies: ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po and ^{210}Pb. Calibration of detection efficiency was performed using EPA radium standard. Concentrations of radon activity were determined on the basis of the intensity of short-living radon daughters ^{214}Bi and ^{214}Pb gamma-lines. All 14 charcoal canisters from each laboratory were exposed under the same conditions next to each other in 14 different places in rooms or classrooms on the ground floor. The activities of radon concentrations were measured in all three participating laboratories on HPGe and NaI detectors independently. Each laboratory corrects the results with calibration factor and with adjustment factor obtained from canisters manufacturer. The results of intercomparison were evaluated by using the u-test which was calculated according to the IAEA criteria. Measurements with u-score lower than, or equal to 2.58, are considered acceptable. Good agreement of results proves conformity assessment with standards and also the stability of the performance of the analytical systems in these laboratories. Limitations, but also advantages and possibilities of application of this method for human exposure to radon estimation are discussed in this paper.

[1] Grey DJ, Windham ST, EERF Standard Operating Procedures for Radon-222 Measurement Using Charcoal Canisters, EPA 520/5-87-005, (1987).

A34

METROLOGICAL ASPECTS OF INTERNATIONAL INTERCOMPARISON OF PASSIVE RADON DETECTORS UNDER FIELD CONDITIONS AT MARIE CURIE TUNNEL IN LURISIA (ITALY)

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In recent years a lot of radon intercomparison exercises has been held; mostly they took place in "radon chambers", in controlled conditions of temperature, humidity and radon concentration.
In 2014 an intercomparison under field conditions at Marie Curie tunnel (Lurisia, Piedmont - Italy) has been held to give to radon laboratories the possibility to test their passive systems under field conditions, which are less controlled and much more challenging.
The radon values in the tunnel were measured with six radon active monitors: 3 Tesys MR1-PLUS, based on a scintillation cell, and 3 Alphaguard (Saphymo), based on a ionisation chamber. All the monitors were previously calibrated at ENEA/INMRI facilities by comparison with reference monitors.
In the present paper a synthesis of the metrological aspects of the monitors calibration is given, with particular attention to:

- the Radon Reference Measuring System (RnRMS) operating at ENEA/INMRI,
- the calibration procedure;
- the quality control system;
- the technical featured of radon active monitors used;
- the dependence of monitors response upon ambient conditions.

In the Radon Reference Measuring System at ENEA/INMRI, a reference atmosphere is achieved by transferring radon gas from a standard radium solution in a vessel with a volume of 112 litres. Two different ENEA/INMRI radon monitors (one MR1-PLUS s/n 50 and one Alphaguard s/n EF1613) have been calibrated with respect to this radon reference atmosphere in independent experiments. The calibration is validated in further experiments using radon sources provided by the Czech Metrological Institute in ENEA/INMRI 1 m^3 radon chamber. About quality control, the two types of active monitors were exposed together in a series of n. 25 experiments and their responses were found on average exactly the same, but with a standard deviation of 1.5 % along the series of measurements. This also corresponds to the limit of precision of the instruments. Dependence of monitors response upon ambient conditions was checked in several experiments and turned out that the most relevant parameter is air density, i.e. P/T. In particular the sensitivity of Alphaguard increases with air density while that for MR1-PLUS decreases. These results allowed to define the correction factors. Generally the calibration of the monitors are carried out at 22°C and 1000 mbar while in Marie Curie tunnel the temperature was 9°C and pressure 930 mbar. So, the correction related to air density effect was considerable. Average difference between Alphaguard and MR1 recording in the tunnel was about 5% and was reduced to less than 1% after correction.

A35

MEASUREMENT OF ^{238}U AND ^{232}TH IN PETROL, GAS-OIL AND LUBRICANT SAMPLES AND RADON AND THORON IN PETROL AND GAS-OIL EXHAUST FUMES BY USING NUCLEAR TRACK DETECTORS. RADIATION DOSES TO MECHANIC WORKERS

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Workers in repair shops of vehicles (cars, buses, trucks…) clean carburetors, check fuel distribution and make oil change and greasing. These workers are also exposed to exhaust fumes when controlling vehicle engines in motion. To explore the exposure pathway of ^{238}U and ^{232}Th and its decay products to the skin of mechanic workers, these radionuclides were measured inside petrol, gas-oil and lubricant material samples by means of CR-39 and LR-115 type II solid state nuclear track detectors (SSNTDs), and corresponding annual committed equivalent doses to skin were determined. The maximum total equivalent effective dose to skin due to the ^{238}U and ^{232}Th series from the application of different petrol, gas-oil, and lubricant samples by mechanic workers was found equal to 1.2 mSv y-1cm-2. Accordingly, to assess radiation doses due to radon short-lived progeny from the inhalation of exhaust fumes by mechanic workers, concentrations of these radionuclides were measured in petrol and gas-oil exhaust fumes by evaluating mean critical angles of etching of the CR-39 and LR-115 type II SSNTDs for alpha particles emitted by the radon and thoron decay series. Committed effective doses due to ^{218}Po and ^{214}Po short-lived radon decay products from the inhalation of petrol and gas-oil exhaust fumes by workers were evaluated. A maximum value of 3.66 mSv y-1 due to radon short-lived decay products from the inhalation of gas-oil exhaust fumes by mechanic workers was found which is within the (3-10 mSv y-1) dose limit interval for workers.

A36

MEASUREMENT OF RADON EXHALATION RATE, NATURAL RADIOACTIVITY AND RADIATION HAZARD ASSESSMENT IN SOIL SAMPLES FROM THE SURROUNDING AREA OF KASIMPUR THERMAL POWER PLANT KASIMPUR (U.P.), INDIA.

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Coal fired thermal power stations; large amount of fly ash is produced after burning of coal. Fly ash is spread and distributed in the surrounding area by air and may be deposited on the soil of the region surrounding the power plant. Coal contains increased levels of these radionuclides and fly ash may increase the radioactivity in the soil around the power plant. Radon atoms entering into the pore space from the mineral grain are transported by diffusion and advection through this space until they in turn decay or are released into the atmosphere. In the present study soil samples were collected from the region around a Kasimpur Thermal Power Plant, Kasimpur, Aligarh (U.P.). Radon activity, radon surface exhalation and mass exhalation rates were measured using "sealed can technique" using LR 115-type II nuclear track detectors. Radon activities vary from 92.9 to 556.8 Bq m^{-3} with mean value of 279.8 Bq m^{-3}. Surface exhalation rates (E_X) in these samples are found to vary from 33.4 to 200.2 mBq m^{-2} h^{-1} with an average value of 100.5 mBq m^{-2} h^{-1} whereas, mass exhalation rates (E_M) vary from 1.2 to 7.7 mBq kg^{-1} h^{-1} with an average value of 3.8 mBq kg^{-1} h^{-1}. Activity concentrations of radionuclides were measured in these samples by using a low level NaI (Tl) based gamma ray spectrometer. Activity concentrations of ^{226}Ra ^{232}Th and ^{40}K vary from 12 to 49 Bq kg^{-1}, 24 to 49 Bq kg^{-1} and 135 to 546 Bq kg^{-1} with overall mean values of 30.3 Bq kg^{-1}, 38.5 Bq kg^{-1} and 317.8 Bq kg^{-1} respectively. Radium equivalent activity has been found to vary from 80.0 to 143.7 Bq kg^{-1} with an average value of 109.7 Bq kg^{-1}. Absorbed dose rate varies from 36.1 to 66.4 nGy h^{-1} with an average value of 50.4 nGy h^{-1} and corresponding outdoor annual effective dose varies from 0.044 to 0.081 mSv with an average value of 0.061 mSv. Values of external and internal hazard index H_{ex}, H_{in} in this study vary from 0.21 to 0.38 and 0.27 to 0.50 with an average value of 0.29 and 0.37 respectively.

The results will be discussed in light of various factors.

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A37

CRITICAL ASPECTS OF THE RADON REMEDIATION IN SCHOOLS IN SOUTH ITALY

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The monitoring of 438 school buildings in the province of Lecce (Puglia region, South Italy), carried out as a part of a measurement campaign, showed an average radon concentration of 215±20 Bq/m^3 [1], much higher than the one estimated for the Puglia region (52±2 Bq/m^3). The data analysis highlighted that 7% of schools required remedial actions. To this end, a plan of remedial actions has been designed and realized.

The remediation plan included a radiometric protocol, consisting in:

- pre-remediation measures (six-month monitoring by SSNTD) to identify frequently occupied spaces with high indoor radon levels;
- short-term measurement, before and after remediation actions, by electret dosimeters;
- post-remediation measures (one year monitoring by SSNTD) to verify the effectiveness of the remedial actions.

In the framework of the remediation plan, several technical documents were prepared to support a training programme addressed to municipal technicians.

Most of the mitigation actions consisted in active soil depressurization (ASD), which mechanically creates suction in the soil beneath the building foundation by means of vertical and/or horizontal piping. In most cases radon level reductions have been in the order of 65-85%.

To optimize remedial actions, the authors paid special attention to:

- economic evaluations, in terms of a more effective use of ON–OFF operating cycles. The longest is the time need to reach radon reference level, the longest could be the off-time of fan and energy saving, and vice-versa;
- suction system management, that means maintenance work for the continuous efficiency of the plants. In fact, with the remediation plant in operation, periodic measurements have suggested that an increase in the radon levels may be due to a decay of fan performances (mainly due to the presence of dust, dirt and moisture). This lead to a difficulty to ensure an adequate protection of workers and people in a public building (such as school) over time. The identification of a trained person in charge to periodically check the good working of the system allow to guarantee a long-term protection from radon exposure.

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A38

EXTREMELY HIGH RADON ACTIVITY CONCENTRATION IN TWO ADITS OF ABANDONED URANIUM MINE 'PODGÓRZE' IN KOWARY

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Based on continuous measurements conducted between 17 April and 16 September 2011 radon activity concentrations changes in different periods of time (hour, day, month, half-year) along two adits No. 19a and No. 19 of abandoned uranium mine 'Podgórze' in Kowary, were studied. Related to registered radon activity concentrations values also the risk of exposure to increased ionizing radiation for two groups of people who spend time inside, either for work or leisure, was assessed.

The adits in Kowary had been chosen due to presence in their interior the highest values of ^{222}Rn activity concentrations documented in Poland. They also meet the criteria for a radiation hazard workplace set by Polish law [3].

The highest values of ^{222}Rn activity concentrations were noted in the object at a time when it was open to visitors, guides and other support staff. The average value of radon activity concentrations regardless of the time stayed in the range of 350 – 400 kBq·m^{-3}. These values were considerably higher than the allowable threshold limit of 0.5 kBq·m^{-3} – 1.5 kBq·m^{-3} recommended for such underground workplaces by international organizations [1, 2].

Confirmed that the selected adits in Kowary are so far the only known underground facilities in Poland, in which the maximum values of radon activity concentrations excess one million Bq·m^{-3}. Recorded values of radon activity concentrations were very stable, low and irregular variables throughout the day, practically every hour and month of semi-continuous measurement cycle. The changes only by two periods of activating mechanical ventilation system for 7 hours between 7 a.m. and 14 p.m. and between 19 p.m. and 2 a.m. in April and in September, were determined. However, the rapid increase of ^{222}Rn activity concentration value to over 800 kBq·m^{-3} occurred after 3 – 4 hours after its deactivating. The highest exposure to ionizing radiation from radon and its progeny should be expected in investigated facilities in Kowary all the year. The effective radiation dose allowed for employees (20 mSv/year) was exceeded several times after a month's work and dose allowed for member of the public (1 mSv/year) was exceeded after a one hour spent inside the tourist adit No. 19a [4].

Due to the most unfavourable working conditions in terms of radiation protection manager decided to close this facility for visitors.

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A39

RECONSTRUCTION OF NATIONAL DISTRIBUTION OF INDOOR RADON CONCENTRATION IN RUSSIA

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The aim of our analysis is reconstruction of distribution as well as estimation arithmetic average of indoor radon concentration in Russia using the data of 4-DOZ Report published under supervision of governmental body Rospotrebnadzor. These annual reports summarize results of radiation measurements in 83 regions of Russian Federation. Within the regional radiation measurement programs, most of the regions conducted measurements of indoor radon equivalent equilibrium concentration (ECC) or radon gas concentration. Annual summary 4-DOZ Report includes the average indoor radon ECC and the number of measurements by regions and by three main types of houses: wooden, one-storey non-wooden, and multi-storey non-wooden houses. All-Russian model sample can be generated by integration of sub-samples created using results of each annual regional program of indoor radon measurements in the each type of buildings (quasi-surveys). Arithmetic mean for each quasi-survey was obtained from the 4-DOZ annual reports. The value of geometric standard deviation (GSD) was chosen depending on the number of measurements in each quasi-survey. The number of generated values of radon concentrations in the sub-samples was normalized by population of the region and the number of measurements in the frame of regional program of indoor radon measurements.

By results of indoor radon concentration distribution reconstruction, all-Russian average indoor ECC of radon isotopes is 24 Bq/m^3. Obtained value of GSD=2.9 reflects both the dispersion of reported average values and model dispersion of indoor radon concentration in the regions. Average indoor radon ECC by region ranges from 8 to 106 Bq/m^3. The 90-th percentile of the distribution is reached at indoor radon ECC 54 Bq/m^3.

The quality of data on indoor radon collected by regional departments of Rospotrebnadzor of Russia require special consideration with regard to applicability for the reconstruction of national distribution of indoor radon concentration. The weak points that diminish the reliability of data are absence of common rigorous requirements on inclusion of the dwellings to annual regional radon measurements program; application of short term indoor radon measurements; absence of information on dispersion of indoor radon ECC in annual reports.

Despite the high uncertainty, reconstructed percentiles of indoor radon concentration distribution can be applied to preliminary consideration of strategy of protection of population of Russia against indoor radon. At the same time, it cannot be a surrogate of the conventional national indoor radon survey. Reliable estimates of national average indoor radon concentration and pattern of distribution should be obtained by means of survey which is based on measurements on indoor radon concentration in a representative sample of dwellings using unified, preferably long term measurements technique.

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A40

MEASUREMENTS OF EQUILIBRIUM FACTOR FOR RADON, THORON AND THEIR PROGENY IN THE INDOOR ENVIRONMENT OF UTTARKASHI, GARHWAL HIMALAYA

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The measurements of Radon, thoron and their progeny concentrations have been carried out in the dwellings of Uttarkashi district of Uttarakhand Himalaya; India using cellulose nitrate LR-115 detector based Pin-hole dosimeter and DRPS/DTPS techniques. By using the concentrations of radon, thoron and their progenies equilibrium factors for radon and thoron and their progenies were calculated. The average values of equilibrium factor for radon and its progeny have been found 0.40, 0.22, 0.31 and 0.22 for rainy, autumn, winter and summer seasons respectively while for thoron and its progeny the average values of equilibrium factor have been found 0.04, 0.08, 0.09 and 0.05 for rainy, autumn, winter and summer respectively. In most of the houses, equilibrium factor for radon and its progeny has been observed below the worldwide value (0.4) of equilibrium factor for radon and its progeny.

The detailed discussion of the measurement techniques and the explanation for the results obtained is given in the paper.

A41

INDOOR RADON LEVELS IN DIFFERENT TYPES OF ROOMS AND BUILDING MATERIALS

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In this study measurements of indoor radon concentration has been carried out in different types of rooms and building materials in a number of 272 measurements in Southern Gezira Locality in the central part of Sudan. in the present study, the indoor radon concentration has been calculated by using CR-39 solid state nuclear track detectors SSNTDs. The radon concentration levels varied from 42 ± 4 Bq.m^{-3} in bed room to 110 ± 9 Bq.m^{-3} in kitchens with an average value of 77 ± 7 Bq.m^{-3}. The concentration values were studied due to the type of building material of the sampling location. From this study we found that mud material constitute the maximum value of 106 ± 8 Bq.m^{-3}, while red brick mixed with cement materials showed the minimum value of 66 ± 7 Bq.m^{-3}. Present indoor radon concentration values are far below than the radon action level (200- 600) Bq.m^{-3} as recommended by ICRP , higher than the world-wide, population weighted, average radon of 40 Bq.m^{-3} as reported by UNSCEAR.

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A42

A PRELIMINARY SURVEY OF OUTDOOR RADON CONCENTRATION IN CHINA

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A nation-wide survey of outdoor radon concentration in China has been sponsored by the Department of Nuclear Safety Management of Ministry of Environment Protection to evaluate the environmental outdoor radon level in 2014. The program was conducted in 33 provincial cities in China in January 2014. Cr-39 passive-type solid-state nuclear track detectors were used in this survey. Each surveyed city was instructed to install 7 detectors, five located in urban areas and two in the suburb. In order to observe seasonal variability and calculate outdoor annual mean Rn concentration, the Rn detectors were retrieved and replaced every three months over the one-year period by the environment radiation monitoring unit of the city. All the quarterly retrieved detectors from 33 cities were collectively etched and the etch-pits were counted in the same conditions for the quality control purpose.

Fig. 1 shows the histogram of outdoor Rn concentrations in the first quarter of 2014 obtained from the 33 cities. The Rn concentrations from Shanghai, Jinan and Nanjing are lower than the detection limit of the Rn monitor for Rn measurement, while the data from the other three cities, or Changchun, Lasha and Shenzhen is unavailable because of time delay in Rn detector shipment or other technical issues. The outdoor mean Rn concentration in China was 15.07±4.51 Bq/m3, ranging from 5.0 Bq/m^3 to 21.5 Bq/m^3. The result was slightly higher than 14 Bq/m3, reported previously [1]. As a whole the result from most of the cities was similar to the previous value measured in the same city. However, the result from some cities, such as Fuzhou, was quite different [2, 3]. The previous data mostly were measured 20 years ago. The difference may be resulted from the city development as well as from the changes in the number and location of the observatories. The survey program will be completed in May of this year. The results will be presented in the conference.

The authors would like to acknowledge the Ministry of Environment Protection for the financial support, and the 33 provincial environment radiation monitoring units for their contributions. We would like to thank Mr. Pan Ziqiang and Mr. Liu Senlin for their technical supervision. Finally, we also thank Mr. Zhou Weihai for his technical support.

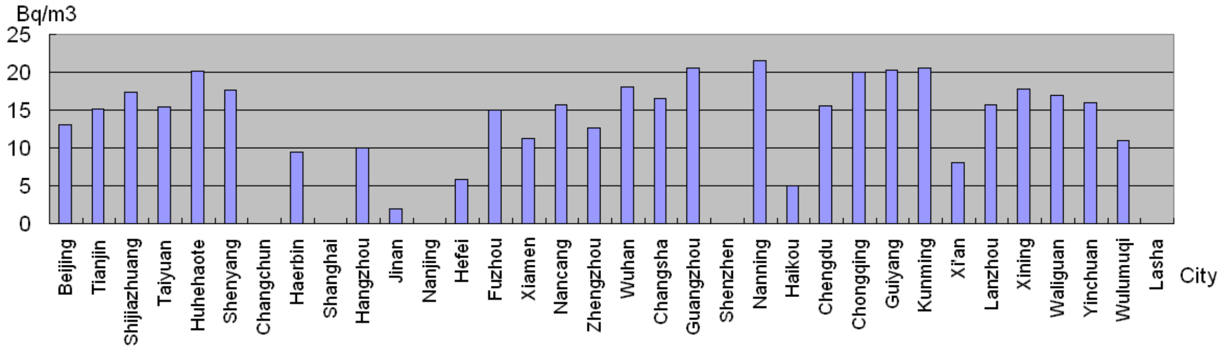

Fig. 1. Histogram of outdoor Rn concentrations in the first quarter of 2014 in China

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A43

RADIOACTIVITY LEVEL IN A URANIUM MINE AREA, CHINA AND ITS RADIOLOGICAL IMPLICATIONS TO WORKERS

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The uranium industry in China develops in a boom in current years as a result of expanding nuclear energy [1]. Consequently, there is increasing attention on the environmental problems as well as workers' health in the uranium industry. With attempt to investigate the radioactivity level and its influencing range, media scale in situ measurements of gamma dose rate exposure in a uranium mining/milling area in Guangdong province, China were conducted. The measurement sites covered miming area, milling area, uranium tailings area and downstream area. A variety of objects in these area including raw uranium ore, fine ore, soil, processing water, wastewater, tailing mud, etc were selected to be measured. The gamma dose rate levels ranged 0.56–34.44 μSv/h with arithmetic mean of 19.23 μSv/h, 0.47–22.77 μSv/h with arithmetic mean of 6.97 μSv/h, 0.52–42.04 μSv/h with arithmetic mean of 17.63 μSv/h and 0.31–4.20 μSv/h with arithmetic mean of 0.96 μSv/h, respectively, for mining area, milling area, uranium tailings area and downstream area. Meanwhile, four soil profiles (1 m in depth) with different distance from uranium tailings were sampled and measured by gamma spectrometer to obtain the activity concentration data of ^{238}U, ^{232}Th and ^{40}K. Then, absorbed dose rates calculated based on concentrations of these radionuclides were compared with the gamma dose rate measured in situ, to understand the contributions of these radionuclides to the absorbed dose rates. The annual effective dose and its radiological hazards for the local workers were subsequently indicated.

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A44

RADON CONCENTRATIONS AND CO_2 EFFLUXES IN MUD VOLCANOES IN SICILY: A PILOT STUDY

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We report the results of a first attempt to monitor the ^{222}Rn emissions from bubbling mud volcanoes of Paternò (Sicily, Italy), by means of solid state nuclear track detectors, CR-39 type, and active devices for continuous monitoring. In particular, ^{222}Rn activity concentrations in soil are correlated with carbon dioxide effluxes, which represents the major contributor to gaseous emissions in this area, in order to investigate about their possible application for geodynamic processes study at the Mt. Etna volcano. Radiometric characterization of soil and water samples are carried out by means of γ-ray spectrometry and liquid scintillation analysis on the basis of samples collected in the whole area. Possible connections between shallow environmental conditions (pressure, temperature) and ^{222}Rn emission from the mud volcano are explored too.

This pilot study opened up new questions for future analysis. Limits and potentialities of the method are currently under investigation in order to develop a well-established procedure to be applied in the study of the other mud volcanoes of Sicily.

A45

INTERNATIONAL INTERCOMPARISON MEASUREMENT OF SOIL GAS RADON CONCENTRATION, SERBIA, NISKA BANJA, 2014

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The presentation is focused on the results of the international intercomparison measurement of soil gas radon concentration, which was held in Niska Banja, Serbia, in May, 2014, as a part of the Second East European Radon Symposium (SEERAS). It describes also the results of the previous survey realized in October, 2013, with the goal to find the most suitable area for the intercomparison.

The test site was chosen after detailed soil gas radon concentration measurements, including repeated sampling in various grids and depths. Due to such detailed measurements, relatively detailed information about spatial variability, temporal changes and variation with depth was available.

The intercomparison measurement was attended by participants representing 12 different institutions. As the intercomparison was anonymous, all data are reported using participants´ codes. Spectrum of sampling and measuring techniques, which were tested during the intercomparison, was large, and the volume of collected soil gas samples was also very variable. The intercomparison measurement was performed under unexpected extreme conditions, because long and heavy rains before the intercomparison caused floods in the vicinity of Niska Banja and influenced substantially the soil properties at the test site, including permeability, effective porosity and water saturation. Such conditions caused serious problems with soil gas sampling and participants representing two institutions decided not to report their results.

Measured values are not reported against a standard or reference measurement, because field intercomparison measurements are not intended to be used as an intercalibration of methods and instruments. Participants´ results are compared to each other and an indication of the collective precision and deviations can be obtained. Data reported by different participants and the variability of results are discussed. Most common errors and failures connected with soil gas radon concentration measurements including soil gas sampling, not only under extreme conditions, are described.

The intercomparison served as a good occasion for every participant to test his own equipment. Regardless of the extreme conditions during the intercomparison, the experiences confirmed the necessity of the preparation and detailed measurements at the test site before the intercomparison.

A46

THORON-SCOUT: THE FIRST DIFFUSION-BASED ACTIVE RADON AND THORON MONITOR FOR LONG - TERM MEASUREMENTS IN BUILDINGS

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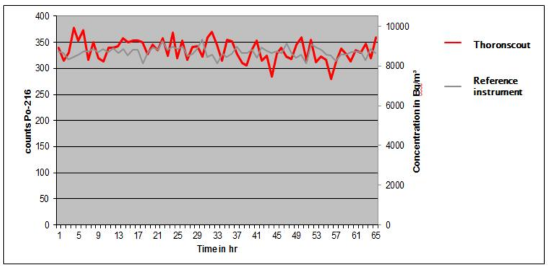
The chemical element Radon has two radiological important isotopes which occur in nature: ^{222}Rn (nat. frac. 90%; commonly simply Radon) and ^{220}Rn (9%; usually called Thoron). Both Radon isotopes and their short-lived progeny are members of natural radioactive decay series. While being the rarest noble gas, Radon is a hazardous constituent of airborne due to its radioactivity. Airborne concentrations of Radon and its short-lived progeny are, therefore, of high interest due to their potential for deposition in the lung. Subsequent irradiation and damage of lung tissue, mainly by energetic alpha particles from radioactive decay of ^{218}Po and ^{214}Po, may induce considerable health risk.

Radon is continuously produced by the decay of natural Radium being a progeny of the natural radioactive isotope ^{238}U while Thoron belongs to the radioactive decay series of natural ^{232}Th. In contrast to Radon, substantially less Thoron reaches the breathing zone because of its much shorter half-life (56 s) compared with that of Radon (3.8 d).

Taking into account the natural fraction in earth crust, half-lifes of ^{238}U and ^{232}Th local geological (or technical) accumulation etc., general health risk of Radon and Thoron may be comparable.

The new Thoron Scout is a real novelty worldwide. The instrument allows the simultaneous measurement of Radon (Rn222) and Thoron (Rn220) based on a diffusion type measurement chamber. The required fast exchange rate of sampled air is realized by a highly permeable chamber placed outside the instruments enclosure. The relative Thoron sensitivity is comparable with the one of pump based instruments. The modified measurement chamber has been derived from the Radon-Scout while the electronics come from the RTM1688-2. That means, more than 2000 data records including a complete alpha spectrum can be stored. Of course, sensors for barometric pressure, temperature and humidity are integrated too. The Thoron Scout offers a larger Display compared with the Radon Scout. The replaceable batteries allow an autonomous operation of approximately one month. It is possible to operate the unit by mains power resulting in unlimited sampling periods. There is also a switch output which can be used for alert purposes or to control ventilation equipment.

Results of the experiments



→ New Thoron detector comparable to pump based reference instrument

A47

THORON IN MODERN CLAY CONSTRUCTIONS – A CASE STUDY

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In the previous years, modern clay constructions were widely promoted for providing healthy indoor climate for their moisture and temperature buffering properties as well as for being ecological and sustainable. It is also well known that clay shows a high emanation rate for radon and thoron compared to typical buildings materials like concretes and bricks. Combined with energy saving measures like air tight windows and roofs, enhanced indoor radon and thoron concentrations were expected, but not widely proofed. After reports in German online-media about thoron emissions and high thoron decay product concentrations in a single clay building, the clay industry as well as customers asked the authorities about the relevance of thoron in such buildings and about the necessity for regulations.

The refurbishment with ecological building materials of an old farmhouse gave the opportunity for a case study. Located in a region with low radon soil gas concentration in the northern part of Germany, the influence of the building materials in this farmhouse should be more prominent. As part of measurements of the general indoor air quality (IAQ), especially of the VOC concentrations and air exchange rates, radon and thoron and their decay products (attached and unattached) were measured time-resolved during two periods in summer and winter. Additionally, long time integrated radon measurements were performed and the activity concentration of natural nuclides of the used building materials were determined.

The potential alpha energy concentration (PAEC) of thoron (average of more than 220 nJ/m³) was considerably higher than the PAEC of radon (around 90 nJ/m³), indicating – together with elevated thoron gas concentration measured directly at the wall surface – a notable thoron exhalation rate from clay. On the other hand, the thorium concentration of the used clays was remarkable low, in the region of only 20 Bq/kg. The dynamic of the measured radon and thoron concentrations challenges the results of simultaneous performed spot and integrating measurements for IAQ.

In this house, thoron leads to a small but notable dose for the inhabitants. A possible restriction on the thorium concentration of clay used for indoor building materials is a necessary but not a sufficient step. Carefully designed ventilation measures are needed to reduce the exposure.

A48

VARIANCE OF RESIDENTIAL INDOOR RADON CONCENTRATIONS: REVIEW AND MODELLING STUDY

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Being able to predict the distribution of radon quantities is essential for planning surveys. The reason is that estimating a statistic within a spatial unit (municipality, grid cell, etc.), such as the mean or an exceedance probability with reasonable precision requires a certain minimal number of samples. The number of samples, estimated by anticipating a distribution, is a centrally important input to the design of a sampling survey. In many cases, it has been noted that the indoor radon concentration within the surveyed territory can be reasonably well approximated by a lognormal distribution. The lognormal distribution is exhaustively characterized by two parameters: the geometric mean as location and the geometric standard deviation (GSD) as dispersion measures. The aim of our work is to suggest typical values of the GSD of indoor radon concentration over a territory. Regarding the physical source of the problem, the dispersion of indoor radon concentrations in a sample of dwellings depends on the variety of physical conditions, which control radon accumulation in a dwelling. The conditions, in turn, depend on a number of factors such as geogenic potential, variety of house construction and dwelling types and living habits. We present theoretical considerations and review the literature about the subject. Data of two particular surveys are analysed in more details with respect to dispersion.

The result of combined analysis of radon surveys in 48 countries shows that the GSD of indoor radon concentration in the sample increases with the average radon concentration, area of territory, heterogeneity of the sample, and shorter measurement duration. The typical world average GSD values are 2.1 and 2.4 for areas smaller than 200,000 km^2 and larger than 200,000 km^2 respectively. Dispersion of concentrations resulting from measurements longer than six months, GSD=2.1, is lower than the one of shorter term measurements, GSD=2.8. As shown for two particular surveys (Sverdlovsk oblast, Russia and Niška Banja town, Serbia) dispersion as quantified by the GSD is reduced if the sample is reduced by making it less heterogeneous. This is achieved by restricting to certain levels of control factors, such as "urban dwelling" or "rural dwellings", or to a smaller area. The amount of reduction of GSD is an indication of the importance of a control factor. The more significant a control factor, the higher is inter-group dispersion on the expense of intra-group dispersion. Reducing of heterogeneity by taking into account the geological factors and building characteristics together results in GSD decrease from 3.4 to 2.3-2.9 (Sverdlovsk oblast) and from 3.9 to 3.2 (Niška Banja). Assuming a GSD=2.7 for a certain area, the minimal required size of a sample for a radon survey to achieve an accuracy of 5% of the arithmetic mean over that area and 7% of the 90-th percentile, is 3000 dwellings.

A49

IN-FIELD EVALUATION OF THE AGEING AND FADING EFFECTS IN NUCLEAR TRACK DETECTORS USED FOR RADON MEASUREMENTS

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Measurements covering one-year period are often used and required by legislation to assess the average radon concentration within a house or workplace. This kind of long-term measurements – generally carried out with nuclear track detectors – can be affected by a sensitivity reduction due to ageing and fading of latent tracks during the exposure period.

In order to evaluate the ageing and fading effects in-field conditions, two different studies were conducted involving two different alpha track detectors: LR-115 films (type-II strippable, from Kodak-Dosirad) and CR-39 plastics (from Radosys Ltd.), largely used within diffusion chambers to measure radon concentration for periods up to one year.

The two studies were part of larger surveys, one carried out in dwellings (~160 rooms) and one in workplaces (~400 rooms of a research center). In these surveys, radon passive devices were generally exposed for two consecutive 6-month periods for each measurement location. In order to evaluate the ageing-fading effects, further devices were exposed in parallel for a single 12-month period in the same locations.

For each measurement site of this sample, a comparison between annual radon concentrations evaluated in two different ways was performed: one obtained as time-weighted average radon concentration between two different 6-month periods; the other one obtained from a single 12-month period measurement.

All device and detectors were manufactured, etched and track counted in the same way. In particular, track counting was made by a spark-counter and by a fully automated image analysis system, for LR-115 and CR-39 detectors, respectively.

A50

STUDY ON RADON CONCENTRATION IN DRINKING WATER AND THEIR PHYSICOCHEMICAL PARAMETERS IN SOME DISTRICT OF KARNATAKA STATE, INDIA

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Water is an essential factor for most life on the planet, and as such the water quality of drinking water is an important parameter for a person's health. Radioactive elements such as radon (^{222}Rn) and radium (^{226}Ra) are found in water. The exposure of the population due to radiation from regular water consumption can be determined by measuring radioactivity in drinking water. Radon is a naturally occurring inert radioactive gas and is a decay product of ^{226}Ra, itself having a half-life of 3.82 days. Radon concentration in water depends on the presence of uranium and thorium in the parent rocks, various grading of rock, type of crystal lattice, dilution by rainwater, temperature and type of aquifer rock.

Radon-enriched drinking water poses a potential health risk in two ways: first, transfer of radon from water to indoor air and its inhalation, and secondly, through ingestion. Inhalation of radon and its short-lived progeny, namely ^{218}Po and ^{214}Po for a long period leads to lung cancer [1, 2]. However, a very high level of radon in ingested drinking water can also leads to a significant risk of stomach cancer. Therefore in view of the above health hazards, monitoring of radon levels in water is necessary for radiation protection purpose and is an important aspect of public health studies as it describes the extent of population exposure to radiation as well as the influencing source water. In the present study radon (^{222}Rn) concentration in the drinking water samples in some parts Ramanagara, Tumkur, Shimoga, Chitradurga and Hassan district of Karnataka state were measured by using Emanometry method (Bubbler method) and the physicochemical parameters were measured by using standard methods. The radon level was found to be higher in the area consisting of granite rocks. The majority of the drinking water samples have radon concentration higher than the maximum contamination level of 11.1 Bq L^{-1} recommended by EPA. In addition to radon concentration, physicochemical parameters of water such as pH, Electrical conductivity, hardness, chloride, sulphate, fluoride, nitrate and TDS were also measured and no significant correlation noted between radon concentration and these parameters.

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A51

INDOOR AND OUTDOOR RADON LEVELS IN AZERBAIJAN

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Indoor radon studies in Azerbaijan the first time have been carried out in 2010-2011 with the financial support of the Swiss National Science Foundation (SNSF). The studies were fulfilled jointly by the Radon Competence Centre (RCC) of the University of Applied Sciences and Arts of Southern Switzerland (SUPSI) and *GGI of ANAS*. About 2500 radon dosimeters were placed in different regions of the country, mainly in residential and in some cases in industrial buildings. Measured radon concentrations varied in a wide range: from almost radon free houses to 1109 Bq/m^3, but about only 7% from total amount of measurements exceeds maximum permissible limits for Azerbaijan (200 Bq/m^3). Based on obtained data Maps of distribution of volumetric activity and elevated indoor radon concentrations in Azerbaijan for the first time were created. These maps reflect mosaic character of distribution of radon and enhanced values of which confine to seismically active areas of intersection of an active West-Caspian fault with sub-latitudinal faults along Great and Lesser Caucasus and Talysh mountains.

Outdoor radon (in soil and in mineral/thermal waters) was the first time investigated in Azerbaijan in last year.

Radon content *in soil* measured within Great Caucasus is changed from trace to 647 Bq/m^3 (average 156 Bq/m^3). On the whole radon content in soil is well agreed with indoor radon level indicated that the first plays main role in formation of radon environment in buildings.

Radon content *in soil over mud volcanoes* (on example Dashgil MV) is changed in limits from 28.3 Bq/m^3 to 13200 Bq/m^3 (average 3045 Bq/m^3). Maximal values of radon are fixed at the foot of forming circular (semi- circular) anomalies.

Results of investigation of mineral and thermal springs within Lesser Caucasus and Talysh mountains allowed establishing the variation of radon values in a very wide range - from 0.4 to 93.3 Bq/l, typical for groundwater, and are substantially chanced in time. The radon level in Talysh area is higher (10.0 Bq/l in average) than in Lesser Caucasus (2.7 Bq/l). The dependence of the radon content from the gas composition of the water has been established: relatively low radon levels are characteristic for nitric, high levels - for carbonic and intermediate values-for methane waters. Radon in mineral waters doesn't pose hazard to human health during taking baths and using as a drinking water. Only in one spring in Talysh area radon level exceeds the maximum permissible concentration for the drinking water more than 1.5 times (according to set standards for neighboring Russia).

A52

REMEDIAL TECHNIQUES FOR RADON MITIGATION IN A RADON PRONE AREA FROM ROMANIA

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Residential radon is the second pollutant after smoking, inducing lung cancer. In the prone radon area of Băița-Ştei Old Uranium Mine [1-3], in the frame of the IRART project (2010-2013), 21 houses have been selected for remediation against radon. The selection was performed from a batch of 303 houses (representing 58% of the total houses from Băita, Campani, Fînate and Nucet localities), following of two campaigns on indoor radon measurements. Analysis of the preliminary data identified the targeted houses having initial indoor radon values between 800 Bqm^{-3}– 2500 Bqm^{-3}.

The remediation techniques have been particularly selected for each house after detailed diagnostic measurements of indoor and outdoor radon, including subsoil, water supply and building materials, identifying the major radon source in each location. The different mitigation methods (e.g. pressurization, depressurization, wind fan extraction, anti-radon membranes and insulation) were firstly tested for a representative pilot-house. The efficiency of the remediation strategy was estimated in each case based on the remediation coefficient (R) through both continuous and integrated measurements.

The final results of the project showed that the applied mitigation techniques were appropriate for our purpose, leading to values of the coefficient of remediation/house in a range of 65.2 - 95.1%, with a medium value of 80.9%. Our results are comparable with the ones obtained in the RADPAR European Project (2009-2012), which involved 14 countries.

The medium radon concentration (992 Bqm^{-3}) of the 21 targeted houses was reduced to a value of 160 Bqm^{-3}. Based on the TF-TR model for the estimation of radon exposure risk, the project implementation will halve the lung cancer cases for the habitants of these houses.

Acknowledgements: The survey was supported by the Sectorial Operational Programme "Increase of Economic Competitiveness" co-financed by the European Regional Development Fund under the project IRART 586-12487, Contract No. 160/15.06.2010, also from PN II, RAMARO Project, Nr. 73/2012

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A53

PLANNING REMEDIAL ACTIONS IN SITES WITH HIGH RADON CONCENTRATION

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Remedial actions are totally necessary in environments where high radon concentrations have been detected. In an initial survey about measurements of indoor radon concentration in working places performed in the region of Extremadura (Spain) several places were detected as having high radon concentrations [1]. Generally, these sites were placed in zones where the natural background radiation is also high [2]. In this way, a deeper study is advisable on the affected zones, performing surveillance and taking remedial actions when necessary.

A project has been started proposing remedial actions. Principal proposed actuations include architectonics actuations, ventilation (when possible), or limiting the time of residence of the people working in the exposed areas (when no other actions can be performed). Several examples of these actions will be presented analyzing each case and the effects that the proposed actions have caused on the changes in the indoor radon concentrations of several places. Studied sites include caves, cellars, historical buildings, hotels or museums. To facilitate the implementation of existing rules and regulations, it is intended to design a protocol for places with high concentration of radon. This plan includes the study of seasonal variations, dose estimations, and the proposed remedial actions.The study has now being enlarged to include also dwellings.

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A54

RADON DOSE PROBLEMS AND SOLUTIONS FOR MITIGATION IN CASE OF SHOW CAVE OF TAPOLCA (HUNGARY) FOLLOWING THE RECOMMENDED REFERENCE LEVEL

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According to new 300 Bq/m3 reference level for radon recommended by IBSS (International Basic Safety Standards) the maximum allowable value becomes strict in non-radiation conditions (radiation workers). We had previously been surveying the changes of radon concentration in the tourist cave's air for 8 years, and had measured the radiation exposure of those working there for 11 years. The current reference level in Hungary is 1000 Bq/m3 for workplaces. It was found that the average radon concentration was 7430 Bq/m3, which greatly exceeds (~7.4 times) the actual reference level and the IBSS recommended (24.7 times) level as well. In addition to natural radon sources of the formation NORM bottom ash (Ra-226 concentration between 500-1300 Bq/kg) can be found in the cave which was used for landfilling. By the end of the year 2011 the filling at the bottom of the cave paths was changed as coal slag had previously been used for. Owing to the Bottom ash removal the annual average radon level was decreased significantly, it was found that the average radon level was 30-40 % lower than before the intervention. Personal dosimetry has being used for 11 years to estimate the dose of employees work in cave. The average number of workers was 12 per year and the average radiation exposure (with dose conversion factor of IBSS No. 115) was 10.6 mSv/year which resulted in a committed effective dose of 18.55 mSv/year calculated using the new recommendation (ICRP publication No. 65). Above 20 mSv/year committed effective dose was found in 6 cases with the IBSS No. 115 whilst applying the new dose conversion factor the actual radiation exposure exceeded the 20 mSv/year value in 44 cases where the average radiation exposure was 28.9 (20.4-53.0) mSv/year.

Keywords: Radon, Radiation workers, Tourist cave, International Basic Safety Standard (IBSS)

A55

A NEW HOUSE BUILT ON THE URANIUM VEIN OUTCROP? NO PROBLEM IN THE CZECH REPUBLIC!

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A significant uranium mineralization at the outcrop of the quartz-uraninite vein hosted in exocontact of the variscan Tanvald granite [1] has been found at the new construction site in the municipality of Jablonec n. Nisou in time of extensive radiohydrogeochemical exploration for radioactive mineral waters in this geological unit realized in 2014–2015.

The ore vein outcrop, where the activity reached 2650 Bq/kg of ^{226}Ra (field gamma spectrometry on surface), is located approximately 10 m above the new house. A quaternary solifluction flow with an increased radioactivity containing ore fragments creeps under the house. The massive aggregates of "gummite" - such as pseudomorphs after the primary uraninite (pitchblende) in quartz; the typical assemblage of uranyl supergene minerals uranophane and metatorbernite are common and resembles the association at the Medvědín uranium deposit [2].

The area was investigated in 1950s during the extensive exploration for uranium with negative results, but quality of the survey was later referred to be insufficient [3].

The main issue is the fact that geologists do not participate in the spatial planning in larger scale. Therefore, localities with a high potential geological risk may become construction sites. It is widely criticized by the geological community not only in the Czech Republic.

Mandatory radon risk survey is then just a mere caricature of a geological work, because most of the companies are not represented by geologists. In any case, toothless radon risk assessment has no power change anything, at this stage.

Problems described above have become a political case at the municipality of the Jablonec city in the meantime. But most of other neighboring parcels have already been sold for the constructions of new houses.

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A56

THE USE OF MULTIVARIATE ANALYSIS AND MODELING OF THE RADON VARIATION IN LABORATORY AND REAL ENVIRONMENT

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Multivariate classification and regression methods are used, as developed for data analysis in high-energy physics and implemented in the TMVA software package, to study connection of climate variables and variations of the indoor radon concentrations. Multivariate analysis (MVA) of the experimental data obtained on the radon concentration and several meteorological parameters shows considerable prediction power of the variations of indoor radon concentrations based on the knowledge of climate variables, only. The results obtained with MVA have led to the development of model which may estimate radon concentration based on meteorological variables. The test of multivariate methods, implemented in the TMVA software package, applied to the analysis of the radon concentration variations connection with climate variables in underground laboratory and real indoor environment, demonstrated the potential usefulness of these methods. It appears that the method can be used with sufficient accuracy (around 15%) for prediction of the radon concentrations. Finally, the online system for MVA prediction of radon concentrations in our Underground Laboratory and testing house is posted online.

The high estimated value of radon concentration would be committing an emergency alarm, upon which appropriate set of measure for radon reduction can be applied.

A57

THE AUSTRIAN RADON RISK COMMUNICATION CONCEPT

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After more than 20 years of dealing with the radon problem, the factors controlling exposure to radon and the methods to reduce radon in buildings are well known. Despite this, the effect of this knowledge in terms of reduction of the radon risk of the population is still very small. This is why in Austria and other countries radon risk communication has become a priority.

To assist in the development of an effective radon risk communication concept a comprehensive radon risk communication document was worked out. This document includes general aspects of radon risk communication, the identification of target groups, and the development of key messages. Furthermore, a comprehensive listing of possible methods and materials for radon risk communication is given. The document also deals with ways to integrate the radon issue in training and continued education of various target groups like building professionals and medical professionals. Finally, possible ways of cooperation with various relevant associations and unions are described.

Based on that concept, target groups and measures were prioritised leading to the selection of specific actions which are to be carried out in the next couple of years.

The presentation will describe the comprehensive radon risk communication concept, the criteria used for prioritisation, and the selected actions.

A58

RADON PROGRAM OF THE CZECH REPUBLIC

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The Radon Program of the Czech Republic 2010 – 2019 – Action Plan[1)] is based on the Governmental Decision No. 594/2009. It is coordinated by the State Office for Nuclear Safety and participated in by governmental, research, and professional institutions. The average indoor radon concentration in the Czech Republic is due to special geological conditions relatively high - of 119 Bq/m^3. That is why protection against exposure to indoor radon is the social responsibility of the state and a professional challenge for specialists. We have some advantages, such as legislation[2,3)], long term experience, scientific and technological background – staff, methods, standards, and a realistic radiation protection point of view. The problem of exposure to indoor radon has been documented in our country for more than 20 years, legal regulation started in 1991. It seems that the public in the Czech Republic is open to accept new information about radon. But our experience related to the interest among the public is not so much optimistic.

The structure of the Action Plan is as follows:

(1) Awareness strategy
(2) Radon prevention strategy
(3) Strategy of controlling existing exposure to radon
(4) Expert scientific and technical support

The priority of the Radon Program is the awareness strategy. The main goal is to inform the public that there is an indoor radon risk that they can influence by their own behaviour and to motivate them to reduce the risk. Besides the main task - involvement and motivation of public, other factors such as economic conditions and the energy saving trends in the construction branch should be taken into consideration. Radon risk shall be taken into account first of all in situations when it can be effectively influenced, such as new house construction, reconstruction, and house purchase. To find the current level of knowledge and risk perception, possible behaviour, expectation etc. we implemented sociological examinations.

In spite of all the positive results protection against exposure to radon is in fact an everlasting task. Behaviour and interest of the public reflect the effectiveness of all the work.

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[3]. Decree of the State Office for Nuclear Safety No. 307/2002 Coll., on Radiation Protection, as amended.

III ERA WORKSHOP **A59**

EU- BSS AND SUMMARY OF THE PARIS HERCA-ASN-NRPA RADON WORKSHOP

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Radon requirements are specified in the European Union Council Directive 2013/59/Euratom of 5 December 2013 laying down Basic Safety Standards (EU BSS) for protection against the dangers arising from exposure to ionizing radiation. In particular, Articles 74 and 103 requires EU Member States to establish reference levels and National Radon Action Plans in dwellings, buildings with public access and workplaces. In addition in Annex XVIII fourteen items to be taken into account in the establishment of action plans are described. These include the strategy for conducting surveys of indoor radon concentrations, the basis for the establishment of reference levels for dwellings and workplaces and the strategy for communication to increase public awareness and inform local decision makers, employers and employees of the risks of radon. An overview is given here of the radon requirements of the BSS and of these issues.

At the end of September 2014 under a joint initiative from ASN France and NRPA Norway, representatives from authorities in charge of Radiation Protection, Health, Labour and Housing and Landscaping in 20 European countries were brought together in Montrouge, Paris at a workshop on national radon action plans within the context of the EU BSS. ERA representatives were also present at this workshop and an account is given here by them of the main findings of the workshop: radon is a public health problem, there is a need for cooperation with all sectors involved on the radon issue to achieve success, action plans must be based on the existing awareness, recommendations to establish regulations, strategies for communication, experiences on mitigation and prevention. The workshop concluded that national action plans should not be static, but evaluated and updated regularly.

A60 III ERA WORKSHOP

A REVIEW OF RECENT NATIONAL RADON PLANS CONSIDERING INTERNATIONAL RECOMENDATIONS AND REGULATIONS

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After the results of epidemiological studies carried out in several countries on risk of lung cancer due to radon exposure, the 2005-2008 WHO International Radon Project has driven a revision of international recommendations and regulations on protection from radon exposure. These includes the WHO Handbook on Radon (2009), the Recommendatios of the Radiation Protections Institutes of Nordic Countries (2009), the ICRP Statement on radon (2009), the European Basic Safety Standards (2013), the International Basic Safety Standards (2014), and the ICRP recommendations on Radiological Protection against Radon Exposure (2014).

In these documents a national radon plan (NRP) is generally recommended or required, in order to better organize the complex set of activities needed to deal effectively with protection from radon exposure. Moreover, many detailed recommendations have been given on the elements to be considered in preparing NRP, taking into account the new regulations and the experience gained up to now. Therefore, several countries have recently set-up or updated their NRP and many other countries are preparing it or discussing about it.

In this paper a review of the recent NRPs will be reported, considering the implementation of the international recommendations and regulations, and highlighting the novelties respect to previous NRPs. Some issues (e.g. effectiveness evaluation) which could be useful for countries that have not prepared/updated their NRP yet will also be reviewed and discussed.

III ERA WORKSHOP **A61**

HARMONISATION PROJECT TO APPLY THE NEW EU-BSS

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The new Basic Safety Standards (BSS) for protection against the dangers arising from exposure to ionising radiation were issued last December 2013. The subject matter of the proposed directive is to establish a Community framework for the basic safety standards for the protection of the health of the people. In particular, the Directive applies to the management of existing exposure situations, including the exposure of members of the public to indoor radon, the external exposure from building materials and cases of lasting exposure resulting from the after-effects of an emergency or a past activity. The Annex XVIII of the document summarizes the list of items to be covered in the national action plan to manage long-term risks from radon exposures.

The European Directive applies to all member states and the radon programs are in different stages of development depending on the country. In the case of Spain, the need for a Radon Program covering the requests from the new BSS includes the existence of laboratories with expertise on radon measurement. Therefore our group in collaboration with ENUSA S.A. (Spanish National Uranium Company) has created a laboratory on natural radiation (LNR) in the facilities of an old uranium mine in Saelices el Chico (Salamanca, Spain).

This laboratory is located in a site where the values of natural radioactivity allow testing instruments and detectors under typically variations of temperature, pressure 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 and holds the first intercomparison exercise under field conditions in May 2011. 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. The Radon Group in collaboration with ENUSA was in charge of the activities of adaptation of this building to the new situation. Radon concentrations and external gamma radiation are subjected to daily variations due to changes in environmental conditions. Thus, the laboratory of natural radiation is the perfect place for the performance of experiments devoted to the analysis of environmental radioactivity as well as a location for testing instruments specialized on the measurement of natural radiation.

A62 **III ERA WORKSHOP**

DIAGNOSTIC PROFILING AS A TOOL FOR MAXIMISING EFFICIENCY OF RADON MITIGATION SYSTEMS

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When preparing a National Action Plan, it is vital that consideration is given to how elevated levels of indoor radon will be reduced once they have been identified. Annex XVIII of the EU BSS Directive states that the National Action Plan should include "Guidance on methods and tools for measurement and remedial measures". Diagnostic profiling of the building is one such method that can be used to aid in the design of a radon mitigation system and maximise the potential efficiency of such a system. This presentation will cover techniques including radon measurement grab sampling and pressure field extension testing, which can be used to identify the optimal location for a sub-slab suction point and highlight whether additional suction points are required.

III ERA WORKSHOP **A63**

CURRENT STATE OF PREPARATION FOR A NATIONAL RADON REGULATION IN SAXONY, GERMANY

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In February 2018 the Euratom BSS regarding radon protection must be implemented in national law.

To be sure that all demands regarding radon measurements and radon protection can be fulfilled in Saxony preparations have already started. A radon protection strategy was developed and since is settled step for step. Core of the strategy is a comprehensive information activity. Beside that several measurement programs (public buildings, schools) provide for advanced knowledge about radon risks and buildings characteristics. These are basis for guidelines and other information material to be developed for house owners and institutions.

One problem accompanying these activities is e.g. that there is no funding planned for radon protection measures. The reason is that radon measures normally are not very costly. Enhanced Radon concentrations in many cases can be decreased with simple measures. As a result the bureaucratic expenses for funding would in most cases be higher than the costs for the measures.

But it is seen as a very important issue to publish sound information material for the measuring part as well as for the constructional part.

Another problem is that there are many open questions regarding radon at work places. Aim of many activities therefor currently is to inform the responsible clientele for all kind of working places according to the EU-BSS. The success of these activities is the basis to avoid subsequent costly control or other activities of the radiation protection authorities.

As a main support in the process the Saxon Radon Information Center will be contact point for concerned citizens.

All activities are taken with the aim to tie information about the problem in the minds of the public and on the background of the awareness that it will take many years to put the implemented regulations into effect. Thus the efforts of today hopefully will help to minimize work and expenses in the future.

A64 III ERA WORKSHOP

MILESTONES IN THE PREPARATION OF A NATIONAL RADON ACTION PLAN IN POLAND

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The new Basic Safety Standards (BSS) for protection against the dangers arising from exposure to ionising radiation were issued last December 2013 (2013/59/EURATOM). According to this document the member states are obliged to implement the new regulations concerning radon and natural radioactivity in their national law. One of the most important issues is the preparation of National Radon Action Plan which deals with the management of existing exposure to indoor radon.

In Poland there haven’t been regulations on radon levels in dwellings and workplaces (except underground workplaces) that could protect the population from exposure to radon and its progeny. In order to fulfil the requirements of EU Directive in Poland, a special team has been appointed by the Ministry of the Environment. The mains task of this team is the development of the concept of EU Directive implementation to Polish legislation, the relevant report is expected till 30 November 2015. Within their activities six groups of experts were created who deal with the different fields covered by he EU Directive. Groups No. 2 and No.5 are appointed to prepare the Directive implementation regarding radon in dwellings and workplaces. The Laboratory of Radiometric Expertise IFJ PAN as representative of „The Radon Centre” Polish scientific network are invited to meetings of those groups as experts. The milestones to develop the national radon action plan are presented together with the indication of arising challenges and risk.

III ERA WORKSHOP **A65**

FIRST STEPS TOWARDS NATIONAL RADON ACTION PLAN IN SERBIA

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Radon problem has a special attention in many countries in the world and the most of them have established national radon programmes. The radon issues in Serbia have not been approached in a systematic and organized way. Currently, there are many research groups and institutions working in radon field and it is a good basis to integrate all these activities into a comprehensive national program to define the strategic objectives and action plan for the next few years. Also, the accession of Serbia to the EU needs to harmonize regulative in the field of radiation protection and this will be one of the tasks we have to perform, and the radon is an important part of that process. In that sense, the group of radon professionals organized Radon Forum, in the May 2014 and made a decision to start work on radon action plan (RAP) in Serbia. The responsibility for the establishment and implementation of RAP is on national regulatory body: Serbian Radiation Protection and Nuclear Safety Agency (SRPNA). We started with internet radon forum (www.cosmic.ipb.ac.rs/radon_forum) which provides an opportunity for radon professionals in Serbia to meet and discuss radon activities and plans. Also, SRPNA formed a "radon working group" that will manage RAP in Serbia. Short-term plans (to the end of 2015) include:

- Develop or adapt the measurement protocol and survey design for long-term measurements.
- Carry out initial representative national indoor radon survey for this purpose.
- Develop communication strategy (first basic information leaflet on radon to accompany the measurement explaining the purpose of the measurement, internet site, public relation …).

In this report, a brief history of radon research, present status and plans for the future activity on radon issues in Serbia are presented. Regarding the long-term plans, the establishment and implementation of an effective RAP is aimed at protecting the public against indoor radon exposures requires input from many national agencies and other stakeholders. These include the national, regional and local organizations responsible for public health and radiation protection. At the end of projected timetable for action plan, the final result must lead to an established national radon programme in Serbia with the primary strategic goal to reduce the overall population risk and the individual risk for people living with high radon concentrations.

POSTERS

P01

STUDY OF RADON, THORON AND THEIR PROGENY IN THE HOUSES OF YAMUNA VALLEY AND TONS VALLEY OF GARHWAL HIMALAYA, INDIA

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Radon, thoron and their progeny concentrations have been measured in the dwellings of Yamuna Valley and Tons Valley of Garhwal Himalaya; India using time integrated solid state nuclear track detector based pin-hole dosimeter and DRPS/DTPS techniques. The radon and its progeny concentrations have been found to vary from 4.9 Bq.m^{-3} to 296.7 Bq.m^{-3} with an average of 42.5Bq.m^{-3} and 2.6 Bq.m^{-3} to 76.1 Bq.m^{-3} with an average of 18.4 Bq.m^{-3} respectively while thoron and its progeny concentrations have been found to vary from 1 Bq.m^{-3} to 121.9 Bq.m^{-3} with an average of 25.5 Bq.m^{-3} and 0.1 Bq.m^{-3} to 3.6 Bq.m^{-3} with an average of 0.9 Bq.m^{-3}respectively.The resulting doses due to the exposure of radon, thoron and their progeny have also been calculated. The measurement techniques and the results obtained are discussed in details.

P02

PRE ESTIMATION OF THE INDOOR RADON CONCENTRATIONS IN PASSIVE HOUSE AND ENERGY-EFFICIENT BUILDINGS

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Radon concentration inside buildings depends on the kind of construction and technology used when building houses[1]. The measures which aim at saving heat energy by room's encapsulation and limiting of the ventilation can lead to a significant rise of radon in these places[2].

This paper presents preliminary results of measurement of the radioactive radon concentration in energy-efficient and passive buildings. The research was conducted on selected houses, based on energy performance certification of buildings[3-5]. Measurement were also done in adjacent buildings constructed with traditional technologies. The point of the work was to compare the radon concentration inside houses with different construction. Specific information about the technics used when building the house, influencing its energy economy were received from the owners.

The research method was long-term direct measurement conducted in 30 properties in 16 locations in Poland. Radon was measured with the method based on diffusion chamber with alpha trace detectors CR-39. Long-term result showed the average value of the radon concentration for the period of the detector's exposure. The maximum and minimal values of calculated concentrations depending on the type of a building are shown in the Table 1.

Table 1. Indoor radon concentrations in passive house and energy-efficient buildings

	Type of a building	passive house	low-enery	energy-efficient	control
	kWh/m^2*year	<15	16-50	51-70	>70
Radon Concentration Bq/m^3	min	21,03	17,54	19,29	14,06
	max	77,52	303,22	104,01	99,97

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P03

RADON LEVELS IN BUILDING BASEMENTS AND ABOVE-GROUND FLOORS AT SÃO PAULO, BRAZIL

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Radon-222, a decay product of Ra-226, is a natural radioactive noble gas that can be found in soil, water and air. Radon and its short-lived decay products in the atmosphere are the most important contributors to human exposure from natural sources [1]. Radon is recognized as the second most significant risk for lung cancer after tobacco smoking. The World Health Organization recommends an average concentration of 100 Bq m^{-3} [2] for radon in air, in order to limit its hazards due to indoor exposure.

The main source of radon exposition indoors comes from Ra-226, a decay product of the U-238 natural series, present in rocks and soils underneath the building and, to a lesser extent, in the building materials. The dynamics of radon production in rocks and soil and its subsequent indoors emanation is quite complex. It is controlled by factors such as soil permeability and water content, meteorological variability, building foundation characteristics and the usual positive differential pressure between the soil and the indoor environment. This is normally sufficient to bring soil gas from the ground into the building. Radon gas can enter a building by several mechanisms, but the most significant ones are diffusion and pressure-driven flow from the ground. Usually, cracks and holes in the floor and walls and gaps around service pipes are the main entrance for the radon gas. Studies indicate that indoor radon concentration present significant variation on the basement, ground floor and upper floors [3].

The aim of this study is to determine the radon levels in building basements and above-ground floors in São Paulo, Brazil. Radon measurements were carried out through the passive method with solid-state nuclear- track detectors (CR-39), because of their simplicity and long-term integrated read-out. The exposure period was, at least, three months, covering one year minimum, in order to determine the seasonal variation of indoor radon concentration.

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P04

THE POTENTIAL IMPACT OF PHOSPHOGYMPSUM PILES ON THE ^{222}RN CONCENTRATIONS ACCORDING SEA-LAND BREEZE PATTERNS IN HUELVA (SPAIN)

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The phosphogypsum piles (PGP) located in Huelva (Spain) have been proven to have ^{226}Ra concentrations 10–40 times higher than background values, i.e. 500–1000 Bq kg^{-1} [1]. Although several previous studies have paid attention to this waste disposal site as a powerful source of ^{222}Rn, the link between the development of mesoscale circulations and the temporal variability of ^{222}Rn measured in Huelva city (sited at about 2.5 km northwest from the PGP) have not been investigated in detail. In this coastal region, mesoscale circulations are mainly characterized by two sea-land breeze patterns, pure and non-pure [2].

This contribution presents the results of investigating the potential impact of phosphogympsum piles on the ^{222}Rn activity concentrations according to these two sea-land breeze patterns. Hourly mean data from April 2012 to February 2013 registered at two sampling sites (Huelva city and in the background station of El Arenosillo, located 27 km to the south-east) have been used in the study.

The results showed a large difference between both stations during the sampling period, 6.3 ± 0.4 Bqm^{-3} at Huelva and 2.99 ± 0.15 Bqm^{-3} at El Arenosillo. The analysis has demonstrated that the highest hourly ^{222}Rn concentrations at Huelva mainly coincided with the occurrence of the pure sea-land breeze. The difference between ^{222}Rn activity concentrations at Huelva city were 9.9 ± 1.5 Bqm^{-3} for the pure pattern and 3.3 ± 0.5 Bqm^{-3} for the non-pure pattern, while in the background station concentrations were 3.89 ± 0.35 Bqm^{-3} and 2.75 ± 0.35 Bqm^{-3}, respectively.

These results suggested the necessary combination of 1) the development of a pure sea-land breeze, 2) the presence of the phosphogympsum piles and 3) the formation of reservoir layers above the sea to justify the high ^{222}Rn activity concentration in this region as well as the notable differences observed between ^{222}Rn values at Huelva and in the background station.

The results have demonstrated that, at the same time, there was a scarce impact on the population, with an estimated annual dose lower than 1 mSv/year, which is a reference level for the public in the majority of regulations.

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P05

PRELIMINARY RESULTS OF INTEGRATED RADON AND THORON MEASUREMENTS AT SNOLAB UNDERGROUND FACILITIES

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SNOLAB is an underground astroparticle laboratory specializing in neutrino and dark matter physics. Located 2 km below the surface in the Vale Creighton Mine near Sudbury, Ontario, Canada, SNOLAB is an expansion of the existing facilities constructed for the Sudbury Neutrino Observatory (SNO) solar neutrino experiment with 5,000 m2 of clean space underground for experiments.

Raduet and NRPB type integrating detectors (using CR-39) were placed at ten different locations in the underground facilities of SNOLAB. The detectors were changed and evaluated in consecutive three months periods starting 9th July 2014. The aim was to gain information about the radon/thoron levels for a whole year and see the seasonal variations. In addition, the performance of these types of detectors under the special circumstances for the underground clean laboratory environment can be studied, where the air pressure is 25% (18.6 psig = 1.28 bar) higher than at surface and rapid pressure swings can occur (up to 5% change in air pressure over 3 minutes).

The preliminary results showed that average radon levels in the given periods measured with these method were under 200 Bq/m3 at all the investigated spots and the thoron levels were negligible in the lab.

P06

RESIDENTAL EXPOSURE ASSESSMENT TO RADON, THORON AND THEIR AIRBORNE PROGENY USING NUCLEAR TRACK DETECTORS

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The long–term measurements of radon (C_{Rn}) and thoron(C_{Tn}) and their equilibrium equivalent concentrations (*EERC* and *EETC*) were carried out in dwellings of Banja Luka city (Republika Srpska) simultaneously using the three types of dosimeter systems based on nuclear track detectors. These were exposed for about 1-year period in the most frequently occupied rooms of 40 dwellings at 15-20 cm distance from the wall or any available room surface. At the end of survey, we obtained results for C_{Rn} and C_{Tn}, in 39 and 19 dwellings, respectively, whereas *EERC* and *EETC* were measured in 36 dwellings. C_{Rn} and C_{Tn} were found to vary from 23 to 206 Bq/m^3 and from 12 to 201 Bq/m^3, respectively. The *EEC* was in the range from 6.34 to 14.41 Bq/m^3 for radon and from 0.10 to 1.1 Bq/m^3 for thoron. The C_{Tn} /C_{Rn} and *EETC*/ *EERC* were in the range from 0.33 to 1.04 and 0.007 to 0.16 respectively.

P07

OPTIMIZATION OF THE PARAMETERS OF THE OPTICAL READOUT OF TRACK DETECTORS USED FOR LONG-TERM MEASUREMENTS OF RADON IN BUILDINGS

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In order to determine the effective dose due to inhalation of radon and its progeny the annual average concentration of radon in the room has to be known. The best method for this purpose is a long-term measurement using track detectors.

In this work radon concentration was measured in a chosen room with the CR-39 track detectors (Radosys, Hungary). At the same time the measurements were carried out by the active radon monitor AlphaGUARD PQ 2000PRO. Track density on the exposed detectors was read using the automatic reading system RadoMeter 2000 (Radosys company, Hungary). The software of this system has several parameters, which are selected for track reading. The aim of this work was to test how the changes of "Focusing" parameter values affect the result of the reading (track density), and therefore the concentration of radon. This made it possible to optimize the settings of these parameters, so that the result of the measurement with track detector is the most consistent with the result obtained by the reference active monitor AlphaGUARD.

It was found that changing the settings of "Focusing" parameter does not significantly affect the result. However, the most appropriate setting is option "Focus All Mode".

Quality and accuracy is much higher when the readout of detectors is made immediately after their etching. Additionally, if detectors were left unprotected after etching and they were read again it was found that the result of radon concentration was significantly lower due to dust deposition on their surfaces.

P08

RADIOACTIVITY OF ANGOLAN ADOBE BUILDING MATERIAL

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Radon (^{222}Rn) and thoron (^{220}Rn) are the daughters of radium-226 and -224, respectively, which are part of the decay chains of uranium-238 and thorium-232. These naturally occur in all soils and rocks [1]. Adobes are building materials made essentially from soils. The main source of indoor radon in dwellings is the ground [2], however, adobe is a significant additional source of radon and most importantly, thoron [3]. In this work we aim to measure and observe the indoor radon and thoron variations in adobe dwellings taking in to account specific climates at areas with different geological background.

Three different localities were chosen in Angola based on their different geography, climate conditions (from North to South and from West to East) and geology: 1. Cabinda at the North-West part of the country which belongs to the geological unit of Pleistocene to Cretaceous marine sediments lying in a series of coastal basins in the western margin of Angola. Here the climate is tropical; 2. Huambo, at the center, which is covered by Archean to Proterozoic rocks form the Angolan, Maiombe, Cassai and Bangweulo shields and the Kwanza's horst. Here we find subtropical climate; and 3. Menongue in the Provence of Cuando Cubango at the South-East belonging to the unit of Tertiary to Quaternary aged sedimentary rocks. Here the climate is semi-arid.

Sixty adobe building material samples were collected from these three areas and 45 houses are being monitored with radon and thoron passive detectors. The building material samples are under analysis for ^{226}Ra, ^{232}Th and ^{40}K activity concentrations using gamma-ray spectrometry and for radon and thoron emanations using RAD7 radon monitor. In-situ gamma dose rate measurements were also performed by an FH 40G-L 10 digital survey meter and the results were varying between 50 and 130 nSv/h in Cabinda, 120 and 280 nSv/h in Huambo and 70 and 160 nSv/h in Menongue.

For a country like Angola, coming from a long civil war what ended only 12 years ago, studies related to radioactivity are novelty. Since more than 30 % of the Angolan population uses adobe as building material, apart from its scientific aspect, this topic has also a great health physics importance and social interest.

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P09

CHARACTERISTICS OF ^{222}RN ACTIVITY CONCENTRATION IN GROUNDWATERS OF THE KACZAWA METAMORPHIC COMPLEX ON THE FORE-SUDETIC BLOCK

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In the paper authors present results of measurements of ^{222}Rn activity concentration in groundwaters occured within the Kaczawa metamorphic complex on the area of the Fore-sudetic block. The Kaczawa metamorphic complex of 4,370 km^2 area is the largest geological unit of the Fore-Sudetic block. As the result of conducted research authors have proved that Kaczawa metamorphic complex is a homogeneous geological unit with regard to the hydrogeochemical background of ^{222}Rn. Minimum, maximum, arithmetic mean, median, and standard deviation values of ^{222}Rn activity concentration are 0.5 Bq/dm^3, 35.3 Bq/dm^3, 9.7 Bq/dm^3, 6.7 Bq/dm^3, and 8,0 Bq/dm^3 respectively. These are selected basic statistical parameters characterizing radon distribution in groundwaters of the examined Kaczawa complex. Similar values of ^{222}Rn activity concentration have been found both, in the Sudetes and on the Fore-sudetic block, i.e within tectonically uplifted and lowered along the sudetic marginal fault parts of the Kaczawa metamorphic complex. In one place, within the outcrop of the Wądroże Wielkie gneisses, authors have found the well with radon water. In this groundwater ^{222}Rn is dissolved in the activity concentration reaching up to 827 Bq/dm^3. This is the highest value ever found on the area of the Fore-sudetic block. This high concentration of ^{222}Rn is probably caused by high ^{226}Ra content in the Wądroże Wielkie orthogneisses – only slightly metamorphosed granites. The outcrop area of the Wądroże Wielkie gneisses looks to be a „radon prone area".

P10

DETERMINATION OF THE AIR CHANGE RATE BY Rn-222 DECAY PRODUCT MEASUREMENTS – PRELIMINARY RESULTS

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Radon (Rn) activity concentration in dwellings strongly depends on the air exchange between outdoor air and different rooms inside the building. Since this exchange can vary, e. g., due to user behaviour, knowledge about the air change rate is very important for a characterization of Rn situation in rooms or houses as a whole. Unfortunately, tracer gas methods, which are commonly used to determine this change rate, are accompanied by considerable technical efforts and cannot be performed during normal usage of an occupied dwelling over a long time.

It would be an elegant way to determine the air change rate as a by-product of the Rn measurement itself. However, attempts to obtain this value from Rn measurements turned out to be not completely reliable in the past [1]. A promising approach is the determination of the air change rate by radon decay product measurements. This is possible since the air change rate term is contained in the differential equations of the radon decay product activity concentrations [2,3]. To develop a usable method, considerations about the stability against different influencing variables are necessary, which can be done by simulations.

A first measurement set-up has been tested successfully in a cottage located in a radon-prone area and the results were checked by tracer gas measurements. For the locally predominating high Rn concentrations a good agreement was observed. The stability of this method against variations of the air change rate was analysed theoretically by simulations. First results with a one-room model showed deviations of only up to 30 % compared to the input mean air change rate values. In addition, simulation studies are currently in progress analysing the stability of the method in a multi-room model with non-steadystate conditions.

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P11

INDOOR RADON MEASUREMENTS IN NY-ÅLESUND, THE NORTHERNMOST CIVILIAN SETTLEMENT IN THE WORLD.

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Ny-Ålesund is situated at 78° 55´ N, 11° 56´ E on the west coast of Spitsbergen, the largest island in the Svalbard archipelago and is a centre for international Arctic scientific research and environmental monitoring. Since 1916 to 1963 was an old coal mining town.

Exposure to indoor radon has been identified as the second leading cause of lung cancer after tobacco smoking. In an indoor environment, there are many factors affecting indoor radon concentrations. Those factors could be different in the Arctic regions. [1]

It is well known that the Council Directive 2013/59 / Euratom of 5 December 2013, article 74, says that "Member States shall establish national reference levels for indoor radon concentrations. The reference levels for the annual average activity concentration in air shall not be higher than 300 Bq m^{-3}" so it is important to know the radon concentration in different places.

Indoor radon activity measurements were carried out in different locations at Ny-Ålesund: Koldewey base (German base), KingsBay dining room, Marine Laboratory, and Gym facilities with five AlphaE devices from Saphymo GmbH. The AlphaE is an ultra small continuous radon monitor for professional use, based on a silicon diffusion chamber.The calculation of dose is possible due to a user-settable equilibrium factor.

Indoor radon measurements were carried out from 3 to 27 September 2014. The values show low average level of indoor radon in the different analyzed buildings, with a geometrical mean of 60 Bq/m^3 with a maximun value of 145 Bq/m^3 in the Koldewey building. So the radiation exposure levels for workers and scientific personnel represents only a low percentage of the exposure guides for the general population.

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P12

CONTINUOUS OUTDOOR RADON MONITORING IN SOME LOCALITIES OF SLOVAKIA

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Concentration of ^{222}Rn (radon) in the surface layer of the atmosphere is not stable. It depends on radon exhalation rate from the soil, intensity of solar radiation, wind speed and other meteorological parameters. Radon concentration in the atmosphere can also vary according to the locality of the measurement.

The measurements of radon activity concentration were carried out on the campus of Comenius University in Bratislava (48°9´N, 17°7´E, 164 m a.s.ℓ.) and in three other localities of Slovakia, which are up to 150 km away from Bratislava. The orography of these localities is different, ranging from flat terrain (Jaslovské Bohunice) to hilly terrain (Nováky).

Radon activity concentration in all localities was measured continuously by scintillation chambers. Outdoor air was collected at a height of 1.5 m above the ground level.

Time series of radon activity concentration in all localities show a similar pattern. High and low radon activity concentrations usually occur at the same period of day. However, radon activity concentrations in Nováky were found to be about two times higher (~12 Bq/m^3) than in other localities. Time shift of daily minima and maxima of radon activity concentrations was also observed between the localities. This effect can be explained by different orography of individual localities.

In Bratislava, outdoor radon has been continuously monitored since 1991. In the period from 1991-2010, approximately 79 000 of radon activity data were obtained. This extensive dataset was used to study average daily and annual time series or radon activity concentration. Composite 24-h radon time series for individual months have a form of waves with the maximum between 4 and 6 a.m. and the minimum between 2 and 4 p.m. Highest amplitudes of these composite time series are reached in summer months (~ 2.7 Bq.m^{-3} in August) and lowest at the end of autumn and during winter months (~ 0.7 Bq.m^{-3} in January and December). Average radon activity concentrations per month show seasonal variations, however the individual years differ from each other quite considerably. On the basis of all measured data, minimum of radon activity concentration occurs in April (3.7 Bq.m^{-3}) and maximum in December (6.5 Bq.m-3), and average radon concentration is equal to 5.2 Bq.m^{-3}. Average radon activity concentrations per year vary from 4.1 Bq.m^{-3} (2004) to 7.2 Bq.m^{-3} (1995). Amplitudes of average daily time series of radon for individual years vary from 1.2 Bq.m^{-3} (2002) to 2.1 Bq.m^{-3} (2008). It was found that the variations of time series of radon activity concentration are in a good correlation with the changes of atmospheric stability.

P13

RADIOACTIVE MINERAL SPRINGS IN THE ST. VOJTĚCH SPRINGS IN HORNÍ MALÁ ÚPA (GIANT MOUNTAINS): THE ACTIVATION PROCESSES

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St. Vojtěch springs in Horní Malá Úpa (The Giant Mountains, Czech Republic) were chosen as a key location for studying activation mechanisms and processes of the high-radon water. 11 springs (HMÚ1–HMÚ11) with different activities (251–5253 Bq/L) in different heights rise here. Geophysical measurement (resistivity methods) confirmed a tectonic zone in the north-east direction which is the source structure of the St. Vojtěch springs. The radioactive springs are in a place where the tectonic zone passes biotite (melanocratic) orthogneiss. This orthogneiss then slowly merges into muscovite (leucocratic) orthogneiss. The dark orthogneiss is in tectonic contact with a small block of partially karsted dolomitic marbles in a substantial part of the spring area. This contact clay zone is impermeable and forms a hydrogeological barrier. Uranium mineralization („uranium leucoxene") in mylonitized melanocratic orthogneiss plays an important role in water activation.

Two quantitative tracer tests were performed to check whether the springs drain a single source for each spring or separate parts of the radon emanating structure. Tracers (NaCl, KI) were injected into the soil in a place with a high infiltration capacity. Springs HMÚ1–HMÚ11 were sampled and analyzed (AAS). The NaCl tracer reached the HMÚ4 spring and KI tracer arrived

at the HMÚ-1. The breakthrough curve was analyzed by Qtracer2 program. The mean tracer velocity was calculated at 0.4 m/h in both cases. This was used for modeling the activation processes.

It was shown that the activity of the springs greatly varies depending on the flow rates. The activity of some springs decreases with increasing flow rate (for example HMÚ-1), in other springs the trend is opposing. The main HMÚ-1 spring was used for studying the activation processes and mathematical modeling. The spring outflow directly in the activation zone is prerequisite. The result is a model of flow rate vs. activity: $A_{v(Rn\text{-}222)} = A_{vs}\,(1\text{-}e^{-\lambda(l/v)})$

$A_{v(Rn\text{-}222)}$ = ^{222}Rn volume activity of ground water [Bq/L]

$\lambda_{Rn\text{-}222}$ = ^{222}Rn decay constant [h^{-1}]

l = length of the activation zone [m]

v = flow rate (calculated on the basis of the tracer tests) [m/h]

A_{vs} = volume activity for very low flow rates or very long activation zone, when radon activity is it in equilibrium with ^{226}Ra in rock (on the basis of this model for HMÚ-1 spring: 4079 Bq/L).

On the basis of this model the activation zone of the HMÚ-1 spring has a length of 49 m.

P14

HYDROGEOCHEMICAL CONSIDERATIONS REGARDING THE FORMATION OF RADON AS A HEALING SOURCE

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There are several spas in Europe where radon is used for medical therapies against different diseases. Often enhanced concentrations of radon in ground waters or brines are found at those places. The reason for high radon-222 concentrations in those fluids are always high enrichments of radium-226 at the surfaces of the aquifer rocks. The hydrogeochemical origin of these enrichments are oxidation and biochemical processes. I.e. these processes can only happen in zones, where the redox potential is at an adequate level. What exactly happens is depending on the particular hydrogeochemical situation of the groundwater and the condition of the rock surface. In general the following reactions and processes may occur:

- (co-)precipitation of radium directly on a (blank or iron-/manganese coated) rock surface
- (co-)precipitation of radium at (in-)organic particles in the aquifer and subsequent fixation/precipitation of the particles at the rock surface
- fixation of radium at micro-organisms on the rock surface
- ingestion of radium by micro-organisms on the rock surface
- combinations of the processes above

Most likely combinations of chemical and microbiological processes take place as a result of a transition of iron and manganese from a more reducing environment into an area with oxidizing conditions. After the death of organisms radium stays fixed in or on the organic matter on the rock surface. After time the organic matter may disintegrate. As a result a coating of ferric or manganic substances enriched with i.a. radium covers the rock surface. Under some hydrogeochemical circumstances also carbonates, sulfates or silicates may develop. But they do not lead to a comparable enrichment of radium as it is the case with iron- und manganese compositions. As groundwater situation did not much change since the last ice-age (ca. 10000 years), such enrich-ment of radium on rock-surfaces led to high concentrations of ^{226}Ra, producing the noble gas ^{222}Rn that can be measured in comparably high concentrations in the groundwater.

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P15

MEASUREMENTS OF NATURAL RADIONUCLIDES AND RADON CONCENTRATIONS IN SOIL GAS IN KOSOVO

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Radon (together with its parent: radium) constitutes the main source of natural radiation exposure for human beings and has been recognized as a carcinogenic gas.

In the present study, the measurements of radon were carried out using the SSNTDs (CR-39) at 25 different locations in Kosovo, at a standard depth of 0.8 m from the soil surface. Sampling frequency was seasonal and sampling locations were randomly chosen. In order to determine the concentration of natural radioactive elements 238U, 226Ra, 232Th and 40K the soil samples were collected from each measuring point from a depth of 0.8 m.

The main objective of the survey was to identify the areas with high radon levels, to correlate it with the soil and meteorological parameters.

From the results obtained, we have found that the region of Dragash had elevated levels of radon concentration that was due to the structure of metamorphic rocks. Also, results showed seasonal variations of the measured soil gas radon concentrations.

P16

SPRINGS OF THE RADIOACTIVE MINERAL WATERS ON TANVALD GRANITE, BOHEMIAN MASSIF, CZECH REPUBLIC

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A large number of new springs of radioactive medicinal water were found in Kralický Sněžník (Orlica Mountains), in the area of the Janské Lázně Spa, Kowary and Horní Malá Úpa (Krkonoše Mountains), in the area of Lázně Libverda–Świeradów-Zdrój and in the Chrastava–Bogatynia area (Jizera Mountains) in the Lusatian unit of the Bohemian Massif [1-3]. The principal source rocks are the Sněžník, Krkonoše, Kowary and Jizera orthogneisses. As a prospective area for new radiohydrogeochemical exploration research in 2014-2015 has been chosen Tanvald granite, which is part of the variscan Krkonoše-Jizera pluton. From other types of granite Krkonoše-Jizera pluton differs by high U/Th ratio and alkaline composition [4]. Radioactive water of the Tanvald granite has been discovered already in the 30s and 40s of the 20th century [5].

New radiohydrogeochemical survey was done in a 17 x 2.5 km area of the whole Tanvald granite body. Indicative gamma activity measurements were performed in 583 water manifestations and 107 of them were chosen for ^{222}Rn measurements. ^{222}Rn volume activity was measured by emanation method. Furthermore were determined also of spring yields, pH, Eh and conductivity. 14 of these springs have a larger value exceeding the activity concentration of the ^{222}Rn content of 1500 Bq/L and fill the criteria for mineral water category (Czech Spa law no. 164/2001 Col.)

An interesting feature is the large variability of the water conductivity (43–3900 µS/cm). The most important discovery is Schindler spring in the Kokonin (2255 Bq/L, 666 µS/cm), which has surprising flow rate of 0.4 L/s. An important area in terms of frequency of radioactive springs is a Dlouhý Most village, where measured already mentioned [5]. Radioactive mineral springs were also found in the area of Rádlo and Černá Studnice.

The survey confirmed premise occurrence of radioactive mineral water at Tanvald granite and confirmed the 70-year-old data presented [5].

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P17

EFFECT ON SEASONAL RADON LEVEL OF THE REMOVAL OF NORM ORIGIN BACKFILLING IN TAPOLCA SHOW CAVE

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In order to reduce received dose originated from radon and its progenies the radon level and its sources ought to be surveyed in badly aerated spaces. The show cave of Tapolca (Hungary) is a frequently visited tourist cave. As a result of 8 yearlong monitoring it was found that the radon level in the air of the mine varied according to seasonal changes. During summer the radon level was above 10000-15000 Bq/m^3, whilst in winter period significantly lower radon activity concentrations were observed owing to natural air exchange phenomena. In addition to natural radon sources of the formation NORM bottom ash (Ra-226 concentration between 500-1300 Bq/kg) can be found in the cave which was used for landfilling.

By the end of the year 2011 the filling at the bottom of the cave paths was changed as coal slag had previously been used for. As a result of bottom ash removal the radon concentration during cold months (November to March) the measured radon concentration was significantly (5-10 times) lower than former periods'.

Owing to the Bottom ash removal the annual average radon level was decreased significantly, it was found that the average radon level was 30-40 % lower than before the intervention.

Keywords: *Radon, Tourist cave, NORM, bottom ash removal*

P18

INDOOR RADON LEVELS IN HUNGARIAN THERMAL SPAS

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According to the new International Basic Safety Standards (IBSS) released in 2014 the recommended reference level in workplaces is only 300 Bq/m^3 to avoid elevated risk of developing lung cancer caused by radon and its progenies. Currently the actual reference level in Hungary is 1000 Bq/m3. In order to keep the new reference level in Hungarian thermal spas to long-term indoor radon measurements were carried out. In this study, the indoor radon concentrations of three of the most popular thermal spas in Hungary were surveyed by both a passive (CR-39 SSNTD) and active (AlphaGUARD 2000 professional radon monitor) method. In case of two spas the annual average radon levels were lower than the recommended level, 183±25 and 174±27 Bq/m^3 in the Medical Parad bath and Igal health bath, respectively. In case of thermal spa in Eger the measured average annual radon concentrations were higher 313±35 Bq/m^3 where the big pool and sparkling baths contain radon concentrations of about 403±42 and 354±33 Bq/m^3, respectively. On the basis of the obtained results it was found that in Eger thermal spa personal dosimetry or radon mitigation will be required if the official reference level will be 300 Bq/m3 to avoid costly official radiation surveillance program.

Keywords: *Radon, Thermal bath, Lung cancer, Radon therapy, Basic Safety Standard*

P19

RADON/THORON EMANATION AND EXHALATION OF SLOVENIAN SOIL SAMPLES DETERMINED BY SIMULTANEOUS MEASUREMENT METHOD USING RADON MONITORS

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The radon isotopes (Rn-222 and Rn-220) and their progenies are responsible more than 50% for natural dose suffered by humans. The survey of Rn-222 (Radon) from various media e.g. building material, soils, by-products are common whilst the Thoron has lower interest owing to its complicated measurement technique. In so many cases the Thoron is a disturbing effect in case of radon measurements.

In this survey the Radon and Thoron emanation and exhalation features were investigated simultaneously originated from the 7 different lithological units, which are the most common in Slovenia. Altogether 50 samples were taken and examined with accumulation chamber technique. AlphaGUARD 2000 type continuous professional radon monitor was used to determine the exhaled Radon and Thoron. The massic radon exhalation (exhalation related to mass) were obtained in case of Radon and Thoron, whilst the emanation factors were derived from secular equilibrium state of Radon and Thoron.

Keywords: Radon, Thoron, massic exhalation rate, emanation, soil

P20

OCCURRENCE OF ^{222}Rn AND ^{226}Ra IN GROUNDWATERS OF THE HOLY CROSS MOUNTAINS REGION IN POLAND

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There is no data about the most important radionuclides' activity concentration in groundwaters of many regions in Poland. The authors measured ^{222}Rn and ^{226}Ra activity concentration in groundwaters of the Holy Cross Mountains region and in groundwaters in a part of the Carpathian foredeep which adheres to the Holy Cross Mountains from SW.

Authors chose waters which outflow from Mesozoic and Paleozoic rocks of the West-European platform, which outcrops are located on the area of Holy Cross Mountains and groundwaters, which outflow from Mesozoic rocks forming a substructure of the Carpathian foredeep.

Authors collected 31 groundwater samples from the Holy Cross Mountains and 11 samples from the Carpathian foredeep (Busko Zdrój, Solec Zdrój, Dobrowoda, Las Winiarski). Groundwaters from the Holy Cross Mountains are mainly ultrafresh and fresh waters as well as acratopegaes. Only one sample has mineralization (TDS) above 1 g/dm^3. On the other hand from the Cretaceous rocks lying under Miocene sediment cover, filling Carpathian foredeep, high mineralized waters with the chemical type Cl–Na (8 samples), Cl–SO_4–Na (2 samples) and brine with Cl–Na chemical type flows out. All of them contain I^- ion in concentration above 1 mg/dm^3. Nine samples contain in significant quantities H_2S: from 12 mg/dm^3 in the Dobrowoda G-1 intake to 93 mg/dm^3 in groundwater taken from the Szyb Solecki intake. Especially noteworthy are two most mineralized groundwaters from Busko Zdrój. These from Małgorzata 19 borehole (brine) and from Henryk 15 borehole (high mineralized water) do not contain sulphides, but contain big amount of Fe^{2+} (28 mg/dm^3 and 21 mg/dm^3, respectively) and F^- (3 mg/dm^3 and 4.3 mg/dm^3, respectively).

^{222}Rn activity concentration in groundwaters from the Holy Cross Mountains area is from 0.9 ± 0.1 Bq/dm^3 (Pasmo Zagórskie) to 78.5 ± 6.9 Bq/dm^3 (spring in the Tumlińskie Hills). In 13 water samples ^{226}Ra activity concentration was measured. Only in four of them the activity concentration of ^{226}Ra was above LLD. The highest measured value is 0.06 ± 0.01 Bq/dm^3 (Silnica spring, Tumlińskie Hills and Św. Franciszek spring in Święta Katarzyna).

The results of ^{222}Rn activity concentration measured in the groundwaters taken from Carpathian foredeep are from 0.7 ± 0.03 Bq/dm^3 (Busko Zdrój, brine from Małgorzata 19 borehole) to 22.3±2.8 Bq/dm^3 (Dobrowoda, G-1 borehole). The values of ^{226}Ra activity concentrations in this region are higher than from the Holy Cross Mountains. The highest level was observed in high mineralized waters: 0.6 ± 0.04 Bq/dm^3 (Henryk 15) and 0.5 ± 0.04 Bq/dm^3 in Małgorzata 19 intake. The lowest concentration was observed in the sample from Aleksander B4a intake in Busko Zdrój (0.11 ± 0.02 Bq/dm^3).

The studies provide a basis to put forward the following conclusions: with increasing concentration of TDS ^{226}Ra activity concentration increases too. In the most mineralized groundwaters authors observed the highest values of this isotope activity concentration. There was no such correlation between ^{222}Rn activity concentration and TDS. Higher values of this isotope's activity concentration were observed in the waters collected in the springs and wells from the Holy Cross Mountains area, in which, in majority, mineralization does not exceed 1 g/dm^3. In these waters the contribution of $^{226}Ra^{2+}$ is small and it can be assumed that the ^{222}Rn dissolves in groundwater as a gas released from the reservoir rocks.

P21

URANIUM AND THORIUM LEACHABILITY IN STREAM SEDIMENT FROM A URANIUM MINING AND METALLURGY AREA, CHINA

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The leachability and potential environmental risks of uranium (U) and thorium (Th) in aquifer sediments from a recent uranium mining area in South China were investigated as a part of ongoing environmental investigations. Data for the non-mineralogical portion of U, Th and of certain additional elements (Mn, Fe, Ca, Mg, Na, Al and K) using a 0.5 mol/L HCl partial leach and Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) were presented for the contaminated sediments and a background sediment. The contaminated sediments reported leachable contents of U between 22.9 and 5170 μg/g and those of Th between 4.8 to 102.1 μg/g, which exceeds by a few to several hundred times the respective content found in the background. Generally, the U and Th contents in the stream sediments decrease as distance from the potential sources increases. A special case is the runoff gathering reservoir located around 1 km downstream of the U mine-site, representing the most severe metal contamination hotspot within the alpine watershed, where the highest leachable content of U and Th in the inlet sediment was observed. The highest leachability of U (68.6%) and Th (44.8%) was observed in this sediment as well, indicating a high potential of bioaccumulation and bioconcentration of U and Th under changing geochemical conditions. Correlations between the analyzed metals and the principle component analysis were then additionally used to identify possible transport mechanisms of U and Th. The results suggest that three factors may explain that the distribution of non-mineralogical U and Th in the sediments: (1) anthropogenic contribution from fluvial transportation of mine waste through streams and aeolian transportation of mineral particles, (2) diagensis processes related to Fe/Mn secondary (hydr) oxides, (3) natural orignin from parental rocks.

Acknowledgments

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P22

THE NATURAL RADIOACTIVITY OF THE CARPATHIAN NATIONAL PARKS AND RADON EVALUATION

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Transcarpathia is a region important from the point of view of the water resources formation and wind flows of Eastern and Central Europe. The chemical and microelement composition of mountain soil and water resources are formed under the influence of geochemical factors and human activities. This explains the importance of monitoring the environment of mountain areas. The mountain protected areas that lowest affected by anthropogenic factors are the ideal object for such studies.

In this report we present the results of the low-background *gamma*-spectrometric measurements of soils probes from the protected mountain areas (Zacharovanyy kray, Chorne boloto, Ihthyological preserve Rika and Uzhanskij National Natural Park) of the Tranthcarpatian, Ukraine. The distances between sampling points in a single protected area were in range 200-400 m with elevation to 300 m, probes were taken from surface, from depth 20 cm and more then 50 cm. Radionuclide identification was made by the γ-spectroscopy technique, where the cooled 175 cm^3 HPGe and 100 cm^3 Ge(Li) detectors, the multichannel amplitude analyzers and the low-background laboratory had been used.

Radionuclides from the U and Th radioactive series could be used as markers for natural or geochemical characteristics of the area and Ra activity concentration determination, [1]. This is possible only in case when secular equilibrium is achieved or almost achieved. Soil sampling was carried out at a depth of 0-20 cm, 20-50 cm, > 50 cm. The gamma-ray lines of ^{214}Bi (609.3 keV and 1120.3 keV) and ^{214}Pb (295.2 keV and 351.9 keV) can be used to evaluate the activity of ^{222}Rn. For ^{220}Rn one can obtain an equivalent Ra content from the detection of ^{212}Pb (238.6 keV), ^{212}Bi (727.3 keV).

The results of these radionuclides specific activities studies in soils probes for protected areas and conditions for the radon content evaluation are discussed. It is shown that soil characteristics cause the features of fixing and distribution of radionuclides in mountain Carpathians areas and leads to the separation of soil depth of the natural uranium and thorium series' radionuclides. The radionuclide composition of the deeper soil samples reflects steady trends of forming their physical and chemical structure. Also it can be assumed that the same trends works for other mountain systems.

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P23

ALPHA RADIATION DOSES DUE TO RADON SHORT-LIVED PROGENY FROM THE INHALATION OF AIR BY SPELEOLOGISTS INSIDE A KARSTIC CAVE

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^{222}Rn is an α-emitting radioactive noble gas produced by the decay of ^{226}Ra, both being members of the ^{238}U decay chain. ^{222}Rn concentrations in soil gas due to continuous ^{226}Ra decay could be very high, with values up to several tens of thousands Bq m^{-3}. Alpha-and beta-activities per unit volume of air due to radon (^{222}Rn), thoron (^{220}Rn) and their progenies were measured in air at different locations inside a karstic cave by using both CR-39 and LR-115 type II solid state nuclear track detectors (SSNTDs). In addition, the concentration of the attached and unattached short-lived radon decay products were determined in the studied cave. The committed equivalent doses due to the attached and unattached fractions of ^{218}Po and ^{214}Po radon short-lived progeny were evaluated in different tissues of the respiratory tract of speleologists from the inhalation of outdoor air. Annual effective dose due to radon short-lived progeny from the inhalation of air by speleologists inside the studied cave was estimated.

P24

ALPHA RADIATION DOSES TO THE EYES OF INDIVIDUALS WEARING OPTICAL GLASSES

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Optical glasses are presently utilized by a great number of individuals to correct vision weakness. Two types of solid state nuclear track detectors were used for measuring uranium (^{238}U), thorium (^{232}Th), radon (^{222}Rn) and thoron (^{220}Rn) contents in various optical glasses as well as radon and thoron in air. Radiation doses to eyes of individuals due to alpha-particles emitted by the ^{238}U and ^{232}Th series inside the studied optical glasses and those emitted by the radon and thoron series in air were evaluated. The influence of the nature of the optical glasses as well as radon concentration in air on radiation doses received by individuals wearing optical glasses was studied. Radiation doses were found higher for persons wearing mineral optical glasses than for those wearing organic optical glasses.

P25

ALPHA DOSES TO INDIVIDUALS DUE TO ^{238}U, ^{232}TH AND ^{222}RN FROM THE INGESTION OF VARIOUS FISH SAMPLES

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Naturally occurring radionuclides existed since the creation of the Earth some 4.5 billion years ago. They are present in rocks, soils, water, air, plants, and animals and even in the human body. According to the Food and Agriculture Organization (FAO), Morocco produces about 1.5 million tons of fish per year. Morocco is the first producer of sardines (sardine pilchardus) in the world. In the present work, ^{238}U, ^{232}Th , ^{222}Rn and ^{220}Rn concentrations were measured in different fish samples collected from different fishing zones in Morocco by using a solid state nuclear tracks detectors method. Alpha radiation doses due to ^{238}U, ^{232}Th , and ^{222}Rn from the ingestion of different fish samples was evaluated. The influence of the consumption rate and fish nature as well as pollution on the radiation doses received by individuals was studied.

P26

INFLUENCE OF SOIL PROPERTIES ON THE MEASUREMENT RESULTS OF RN-222 ACTIVITY CONCENTRATION IN THE AIR ABOVE THE GROUND

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Radon is one of the main sources of the radiation dose received by the people. It quite easily moves to the atmosphere. To determine the risk originating from radon exposure, its content in air above the ground should be monitored. The process of radon exhalation from soil is complex and depends on many factors, which are not fully investigated.

The influence of physico-chemical arable soil properties on Rn-222 specific activity concentration in the air above ground surface was investigated. Activity concentration was measured using AlphaGUARD radon monitor. In chamber, gas temperature T, its pressure p and relative humidity w were also determined. The following parameters in soil samples were determined: current mas (w_{am}) and volume (w_{av}) humidity, momentary volume density d_V, momentary actual density d_r, capillary water mass capacity V_{wm}, capillary water volume capacity V_{wv}. The parameters were determined directly, using Kopecky cylinders.

The results were used in the linear model construction, which describes Rn-222 specific activity concentration a in air close to the soil surface. Among the models studied, the following was the best:

$$a = \beta_0 + \beta_1 w_{am} + \beta_2 T + \beta_3 w$$

The calculated coefficient of determination was 0.775. The structural parameters $\beta_0 - \beta_3$ were different than 0 with the confidence level not bigger than 0.0031.

Besides β_0, the remaining structural parameters were negative. Increase in explanatory variables values produce decrease in Rn-222 activity concentration in air close to the soil surface.

Though the proposed relationship describes changes in Rn-222 activity concentration quite well, it must not be used for explanatory variables values exceeding the appropriate range.

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ASSESSMENT OF RADON EXHALATION RATES AND EFFECTIVE RADIUM CONTENT IN SOIL SAMPLES OF ALEXANDRIA CITY, EGYPT, USING PASSIVE DETECTING METHOD

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This study aims to assess the environmental hazards from radon exhalation rate in the soil samples in selected locations in Alexandria City, using passive (LR-115 type II) detector. Ionizing radiation exposure experienced by the general population is mainly due to the indoor radon. Major part of radon comes from the top layer of the earth. The radon emanation is associated with radon and radium in the soil. Effective radium content and radon exhalation rates in soil samples were measured by ''Sealed Can Technique'' using LR-115 type II plastic track detectors. The soil samples were collected from different locations from Alexandria city, in Egypt. The values of effective radium content were found to vary from 2.7 to 53.80 Bq/kg with geometric mean value 13.28 Bq/kg, and standard deviation of 2.81 Bq/kg. The mass and surface exhalation rate were found to vary from 18.2 to 365 (Bq/kg. h)$\times 10^{-3}$ and 0.83 to 16.63 Bq/m^2. h, respectively. All the values of radium content in soil samples of study area were found to be quite lower than the permissible value of 370 Bq kg^{-1} recommended by Organization for Economic Cooperation and Development.

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PROTOTYPE PRIMARY STANDARD SOURCE OF RADON ACTIVITY CONCENTRATION

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In the last years, there were many experiences conducted to primary and secondary standard source of radon in different laboratories in all over the world. Radon standard source mainly based on type of measurement techniques and nature of calibrated devices. In order to calibrate measurement devices for monitoring of activity concentration of ^{222}Rn in dwelling and air, a prototype of a calibration facility has been tested. The radon standard source constructed on the base of solid ^{226}Ra emanating source and high purity germanium detector (HPGe detector) is presented in Figure.

Emanation box (0.21 liter) is installed on HPGe detector for online gamma measurement. Inside this box ^{226}Ra standard source is installed (32.8 kBq ±3%). Radon monitor AlphaGUARD connected with small emanation box with pumping system (1 liter/min) in open flow mode. Radon concentration is measured in flow open mode each 10 min and gamma spectrum is measured contineously during time intervals 20 min. The emanation coefficient of ^{226}Ra emanating source was controlled online by the measurements of ^{214}Bi (E_γ =609.3keV) activity in the source and comparing measured value with the activity of ^{226}Ra in the source. The stability of gamma spectrometry was controlled by standard ^{137}Cs source installed in emanation box.

This work presents correlation between online alpha radiometry (AlphaGUARD) and gamma spectrometry (HPGe detector). Activity of ^{214}Bi is calculated using HPGe detector polynomial efficiency with systematic error 2.7 % and random error, in each measurement, less than 2%. Correlation between gamma measurements and AlphaGUARD was 91±3 %. Such correlation is within the uncertainties of AlphaGUARD calibration. To improve the accuracy of comparison calibration of AlphaGUARD on national radon standard is needed. It is demonstrated that this type of calibration source can be used as standard source with sufficient accuracy to calibrate working devices.

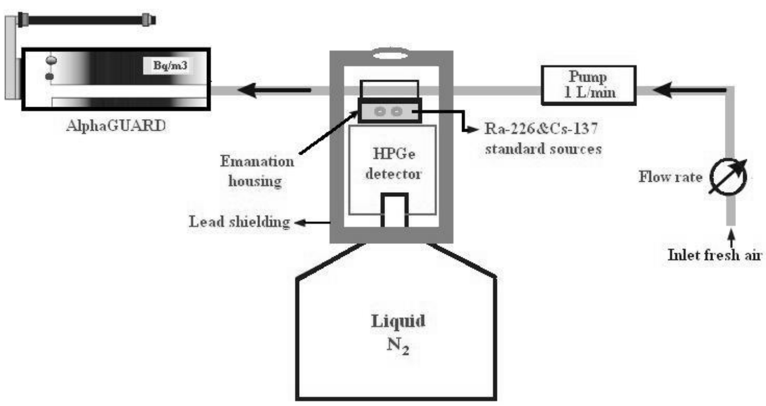

Figure. Experimental setup.

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PRELIMINARY RESULTS OF RADON SURVEY IN THERMAL SPAS IN V4 COUNTRIES

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Radon (^{222}Rn) activity concentrations in thermal waters, consequently in spas, differ in a rather wide range. ^{222}Rn concentrations in some thermal waters can exceed 1000 Bq/l, however this concentration is not constant. Radium activity in some thermal waters is hundred times as high as in normal waters. The use of thermal water in the balneotherapy process contributes to radon release from water into indoor air of the workplace. Radon activity concentration can reach high values due to large volumes of water used. In spas the professional staff is exposed for a longer time than the visitors and effective doses they get may vary from several units to tens mSv per year [1, 2]. In V4 countries (Czech Republic, Hungary, Poland and Slovakia), there is a long tradition in using thermal waters in spa care. The aim of the project of International Visegrad fund was the study of radon concentration in selected thermal waters and thermal spas in V4 countries. Indoor radon concentration was monitored using of passive track detectors [3]. The measurements of radon in thermal waters, which are used in spas, were carried out, too. Each country measured radon in water by own methods. However, the international intercomparison measurement of radon in water was realized [4].

The preliminary results of the measurement of indoor radon in spas (the period: from March 2014 to May 2014) showed that in 84 % of spas radon activity concentration is less than 400 Bq.m^{-3}. However, rooms with radon activity concentration exceeding 1000 Bq.m^{-3} were found in Czech Republic and Slovakia as well. Preliminary analyses indicated that the highest radon activities in spas were found in rooms with the thermal pools. Radon concentration in waters used in spas ranged from 0.5 Bq/l to 250 Bq/l.

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P30

INDOOR AND OUTDOOR BACKGROUND GAMMA RADIATION IN THE URBAN SPACE OF WROCLAW, POLAND

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The attempt to estimate indoor and outdoor background gamma radiation resulting from the presence of NORM in the urban space of Wroclaw (the fourth in terms of population city in Poland) was undertaken. A total number of 43 indoor and 43 outdoor measurements were performed.

Measurements were conducted by means of portable gamma spectrometers RS 230 with a BGO detector which displayed concentrations of K (%), eU (ppm) and eTh (ppm). Indoor measurements were performed in dwellings made of various building materials. Each homeowner received a questionnaire with questions about building materials used for the construction of a building, the construction year, the floor and the time spent in a dwelling. In each dwelling measurements were performed in the corners of four rooms (living room, bedroom, kitchen and bathroom). The device was placed one meter above the floor level and one meter from each of the walls. Outdoor measurements were performed outside investigated buildings. The gamma spectrometer was placed one meter above the ground level and a few meters away from the buildings to avoid as much as possible the impact of building materials used for the construction of walls. The type of material covering the ground was noted.

Specific activities of ^{40}K as well as ^{238}U and ^{232}Th decay series, gamma dose rates in air and the contribution of K, U and Th in forming absorbed dose rate were discussed. The results were compared to the published data [1,2]. The indoor absorbed dose rate ranged from 68 to 142 nGy h^{-1}, with the mean of 110 nGy h^{-1}. No correlation between absorbed dose rate and the construction year as well as the floor was observed. Absorbed dose rate varied depending on the type of the main building material used for the construction of walls. The outdoor absorbed dose rate ranged from 27 to 104 nGy h^{-1}, with the mean of 53 nGy h^{-1}. No correlation between absorbed dose rate and the type of material covering the ground (asphalt, concrete, grass) was observed. The average indoor to outdoor ratio was equal to 2.1, whereas the worldwide ratios ranged from 0.6 to 2.3 [1]. Assuming that people spent 80% of time indoors and 20% of time outdoors [1] (this research indicated that the proportion of time spent indoors and outdoors by people in Wroclaw is 90% and 10%, respectively) the average annual effective dose rate was calculated and determined as 0.60 mSv.

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P31

RADON PENETRATION THROUGH INSULATING BUILDING MATERIALS

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The presence of radon in the environment is a natural phenomenon. Prolonged exposure for radon, e.g. at home in excess of 100 Bqm^{-3}, can be the cause of significant increase of the risk of developing lung cancer [1]. One way to reduce radon penetration into homes from the soil is the use of suitable insulating materials. The aim of this study was to determine the rate of diffusion of radioactive gas ^{222}Rn through layers of building materials used in family- and multi-family construction.

We made a special measuring chamber with a hole with a diameter of 16 cm to which was attached the test material. The chamber was placed in the radon chamber. Measurements of radon concentration in both chambers was measured by scintillation counting. To calculate the rates of diffusion of radon through the insulating material given in ms^{-1} it was used the solution (model) given in the report Roland Löfström, Energy Technology, cj, Norway. The numerical methods were used to solve the equations. We tested 10 pieces of the materials used in construction, roofing and film mainly hydro-and vapor barrier. Radon diffusion coefficients varied in a range 9•10-7 to 1.1•10-6 ms-1 for different materials. For comparison, the rate of radon "diffusion" through the naked hole is $0.6 \cdot 10^{-3}$ ms^{-1}. In December of 2013 the European Union Directive appeared. This Directive contain the regulations of the levels of radon in the room, both the employee and the building [1]. Adjustments must be made into the legislation until the February 2018 year. Implementation of the Directive will cause in many cases the need of reduce the penetration of radon from the ground into buildings. Latest measurements in Poland showed that the annual average radon concentration that exceeds of 100 Bqm-3 is common [2]. The annual average radon concentration for Poland is 170 Bqm^{-3}**.**

It follows that the investigation of the permeability of radon through building materials should be of interest alike to research centers, government and individuals producing building materials.

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SOIL HEAT FLUX AND AIR TEMPERATURE AS FACTORS OF RADON (Rn-222) CONCENTRATION IN THE NEAR GROUND AIR LAYER

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Daily and annual dynamics of Rn-222 concentration in the near ground air layer with reference to meteorological conditions (e.g. soil heat flux, soil humidity, air temperature in the layer 0.2 m–2.0 m a.g.l., wind speed, atmospheric pressure) were investigated in Central Poland in the period 2008-2010 [1, 2]. The research area comprised two sites with different microclimatic conditions - centre of Łódź (typical urban station) and rural, agrarian area in Ciosny village (25 km north of Łódź). The continuous, synchronous measurements of Rn-222 concentration in Łódź (urban station) and in Ciosny (rural station) were made using AlphaGUARD® PQ2000PRO (ionization chamber, diffusion mode, Genitron Instruments GmbH). The device was set up in a meteorological box at a height of 2 m above the ground. Simultaneously soil heat flux (QG) was measured by means of HFP01 Heat Flux Plate, Campbell Scientific Ltd. Recognition of temporal variability of Rn-222 and selected meteorological variables served to create a statistical model for estimation of this radionuclide concentration at 2 m a.g.l. QG and air temperature were characterized with apparent daily cycle and the strongest statistical relations with Rn-222 concentration.

The present study focuses on the description of relations between daily variability of Rn-222 concentration and two meteorological variables – QG and air temperature at 2 m a.g.l. In general, the daily course of Rn-222 concentration is an inversion of air temperature course and it varies approximately in phase with the soil heat flux. The description of relations between variables for individual months was established on the basis of exponential function and exponential function with time derivative of predictor to account for the hysteresis issue. Model with time derivative provided better results. The weakest fitting of modelled data to empirical ones is noted for winter months. During subsequent seasons air temperature as well as QG driven models exhibited very high agreement with empirical data. The restriction in the usage of QG for Rn-222 concentration was observed only in winter in case of snow cover occurrence which reduces daily QG variability.

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EMPIRICAL CDFs OF RADON AND ITS PROGENY CONCENTRATIONS INDOORS IN DIFFERENT VENTILATION CONDITIONS

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The present study concerns changes in the concentrations of radon and its attached and unattached progenies in an occupied and unoccupied auditorium at different air-conditioning (AC) system operation modes. The measurements were carried out in an air-conditioned auditorium at the Lublin University of Technology in Lublin, Poland during several weeks in the spring of 2012 and the fall of 2013 and were performed using the EQF3220 monitor (SARAD, Germany) [1, 2]. Fig. 1 shows exemplary empirical cumulative distribution functions (CDFs) of radon concentrations during different AC system operation modes and at variable ventilation air flow rates. The CDFs of the attached and unattached radon progeny concentrations during different AC system operation modes are presented in Fig. 2. It can be observed that the lowest concentrations of radon and its progenies prevail in the AC on mode, with the amount of the supplied ventilation air having an impact on the concentration distributions. The distributions of radon and its progeny concentration variability were compared using the Cramér-von Mises two-sample test. The analysis of the shape of the empirical CDFs along with the analysis of the variability of the concentrations of radon and its progenies and the determined *F* values could be of importance in assessing health hazards in air-conditioned promises.

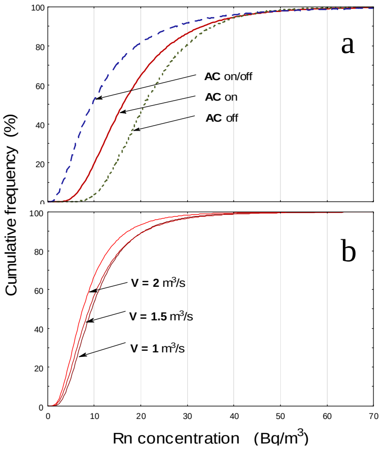

Fig. 1. Empirical CDFs of radon activity concentrations during different a - AC system operation modes, b - ventilation air supply rates.

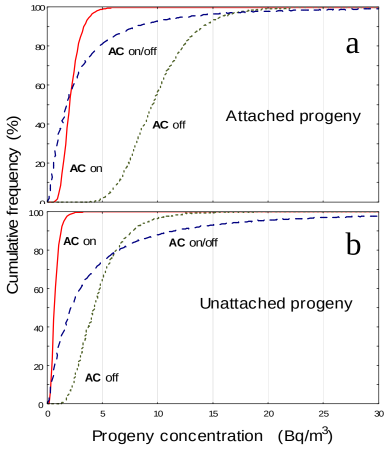

Fig. 2. Empirical CDFs of a - attached radon progeny concentrations, b - unattached radon progeny concentrations.

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P34

ESTIMATION OF WATERBORNE RADON ACTIVITY AND RESULTING DOSES IN SPRING WATER OF MUZAFFARABAD

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Sustained exposure of elevated levels of radon is associated with increased risk of lung cancer in public. It is believed that radon gas is second leading cause of lung cancer. Radon in drinking water can also present risk of developing internal organ cancers, like stomach cancer. However water dissolved radon poses less risk as compared with radon in indoor air. Water borne radon contributes to total inhalation risk associated with radon in indoor air through showering, washing clothes, and flushing toilets. In current study results of water borne radon activities for 60 spring water samples are presented. Water samples were collected from and outskirts of Muzaffarabad city and analyzed by RAD7. From the measured values of radon concentrations in water, ingestion and inhalation doses were calculated and estimation of risk associated with water borne radon activity has been made. Results obtained from current study have been compared with data present in literature.

P35

RADON RISK FOR INHABITANTS OF RYBNIK TOWN, THE CASE STUDY

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The results of the radon studies, performed in the Upper Silesia Region in Poland, have shown that radon indoor concentration levels depend first of all on the geological structure of subsurface layers. However, significant variations of radon potential have been found for sites, located on similar geological structures and experiencing comparable mining effects. An example of such an area is the Rybnik town (Southern Poland, Silesian Province)

In this paper results of radon measurements in dwellings in the area of Rybnik and it's vicinity are presented. Measurements in 59 buildings (in basements and at groundfloor level) have been performed within several campaigns in the period 2005-2009. The measured radon concentrations were within the range from 10±10 to 390±40 Bq/m³ at the groundfloor level and from 20±10 to 740±50 Bq/m³ in basements. The average values of measured concentration were as follows: 80 Bq/m³ for groundfloor's dwellings and 138 Bq/m³ for basements.

In the paper the specific case of one of the buildings with elevated radon level is described. Available information related to the local geology of the site and to an impact of mining activity was collected. Additionally, details concerning the construction of that building were gathered together with the description of life habits of dwellers.

P36

THREE YEARS OF CONTINUAL RADON MONITORING IN THE VAŽECKÁ KARST CAVE, SLOVAKIA

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High resolution continual radon monitoring in the Važecká cave started in June 2012 and is still being carried out. A temporal variability of radon and environmental parameters measured inside and outside the cave was analyzed. Radon concentration in cave atmosphere exhibited seasonal, non-periodic short-term and periodic daily variations. Seasonal trend is characterized by the highest radon concentration in summer months, from June to September, when radon activity concentration was relatively stable and the daily average values ranged from 3.0 to 5.3 kBq/m^3. In the rest of a year the short-term variations lasting 4-13 days were observed and the daily average radon concentration varied from 1.0 to 4.3 kBq/m^3. Seasonal variation of radon is associated with the seasonal change in the difference in internal and outside air temperature. No correlation of radon short-term variation with atmospheric pressure was observed. Regular daily variations of radon can be influenced by cave ventilation caused by the entry of visitors.

P37

RADON IN THE DRY CARBON DIOXIDE SPA OF MÁTRADERECSKE, HUNGARY

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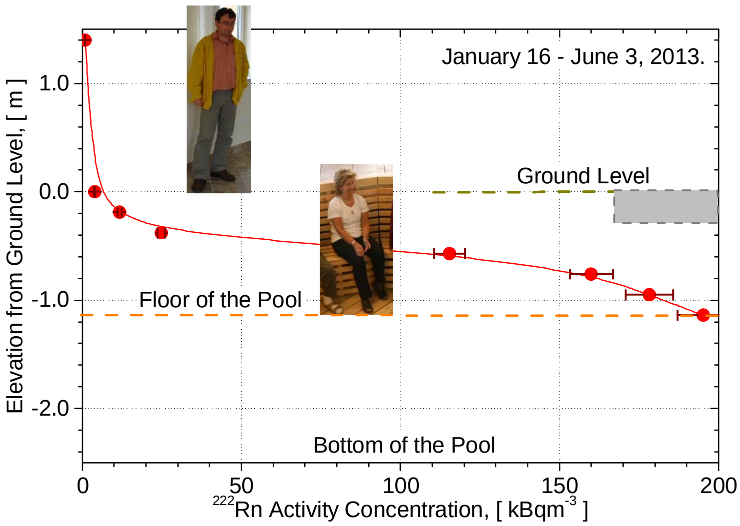
The final product of post-volcanic activity is the carbon dioxide gas, which is called dry mofette. Examples of mofettes are the Torjai-Büdös-cave in Transylvania, Romania or the carbon dioxide seepage in Mátraderecske, Hungary. Along its pathway to the surface the deep origin gas also intakes different radon isotopes from the rocks and soils. Therefore the variation of surface radon exhalation can be a tracer of spots of carbon dioxide outgassing, which occurs most at near surface faults.

On the other hand, mofettes are often used for therapeutic treatments in the form of dry carbon dioxide spas, where the risks, associated with radon exposures should also be a concern. The aim of this work was the study of spatial and temporal variation of radon in in the dry carbon dioxide spa of Mátradercske, Hungary, and the analyses of the results in environmental physical, geochemical and environmental radiation protection points of view.



We have found that the ^{222}Rn activity concentration in the mofette gas in Mátraderecske is very high, it is in the order of 200 kBqm^{-3}. In the pool of the spa it decreases with distance from the bottom of the pool as the carbon dioxide mixes with fresh air. The ^{222}Rn activity concentration at the mouth level of patients is a few kBqm^{-3} and it is about 1 kBqm^{-3} at the mouth level of the staff. Radon exposures are estimated both patients and staff.

P38

METHOD TO DETRMINE RADON-CONCENTRATION IN TAP WATER

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Rocks and soil are containing naturally occurring radioactive materials. Due to solution and transport processes these radionuclides are attained to tap water. One of these radionuclides is radon-222 which is a progeny of radium-226. Rn-222 is of good solubility in water.

Tap water containing high concentrations of Ra-226 respectively Rn-222 can lead to increasing radiation exposure. In this project a method for the chemical separation of radionuclides is presented. After identifying the radionuclides and their activity it is possible to give an estimation of the possible radiation exposure.

In a first step the water samples are set up to a pH-value around 2. Afterwards phenolphthalein as an indicator is added. Then the dissolution is heated and diammoniumhydrogenphosphat is added. As a result precipitation is falling out, to support this reaction pure ammonium can be added. The precipitation will be separated from the solution and is dryed. In a last step the precipitation is solved with hydrochloric acid, a scintillator liquid is added and the dissolution is measured in a liquid scintillation counter (LSC). As a result alpha and beta decays can be registered and the contained radionuclides can be identified.

The project is a cooperation of the EGE University Izmir, the Justus Liebig University Giessen and the University of Applied Sciences Giessen to determine persistent organic pollutants, metals and heavy metals and radionuclides in tap water of the region around Aliaga, Turkey.

P39

UPDATE OF RADON CONCENTRATION MEASUREMENTS IN DWELINGS IN THE REPUBLIC OF MACEDONIA

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As part of the study of the variability of indoor radon concentration, new measurements were performed in 16 cities in the Republic of Macedonia. CR-39 nuclear track detectors, commercially named RSKS and provided by Radosys Company, were deployed in 43 dwellings in the most occupied room on ground floor and exposed between January and March 2013. Measured radon concentrations from this survey were in the range from 30 to 535 Bq/m^3 with geometric mean of 114 Bq/m^3.

The linear regression analysis was applied on results measured in winter season and annual ones, reported in the National survey for ground floor dwelings in these cities. The obtained linear model with high Pearson coefficient of determination R^2 = 0.924 and with uncertainty of function fitting of 2% was used to estimate annual radon concentrations in this new survey.

The annual concentrations in the new survey were in range from 26 to 460 Bq/m^3. The obtained geometric mean value (98 Bq/m^3) is almost equal with geometric mean of annual radon concentrations of National survey in these cities (99 Bq/m^3). This new survey also confirmed the influence of presence of basement and buildings materials on indoor radon concentrations.

Our results show that apparently a low number of relatively short term measurements are able to reasonably reproduce the results of the larger National Survey.

P40

RADIOACTIVITY OF THE "GRZMIACA" TAILING IN GLUSZYCA GORNA (SW POLAND)

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The aim of this research was to evaluate radioactivity of Grzmiaca tailing and its influence on the level of atmospheric radon concentrations and total doses of radiation noted in its vicinity.

Grzmiaca tailing is located in southwestern Poland in a small village called Głuszyca Górna. The tailing was formed during uranium excavation lasted from 1956 to 1959. The uranium mineralization in this region is mainly connected with grey-green conglomerates and sandstones of the Glink Formation [1]. Nowadays, the tailing is mainly covered by grasses and small trees apart from the upper part which is only covered by soil and crushed rocks.

Radiation dose rates, atmospheric radon concentrations and contents of uranium, thorium and potassium were measured. Surveys were performed in 32 places, 8 measurement points were located in the tailing. The most distant measurement point was situated about 750 m from the tailing, near the railway station in Głuszyca. Measurements of radiation dose rates were carried out using radiometer EKO-D. Measurements of atmospheric radon concentrations were performed using Solid Nuclear Track Detectors Kodak LR-115 placed inside diffusion chamber and exposed at the height of 1.5 above the ground. These detectors were exchanged after 3-4 months in order to notice seasonal variations of radon concentrations. The surveys of eU, eTh and K contents in the bedrock were conducted using spectrometer gamma RS-230.

We observed that radiation dose rates in the tailing varied from 0.35 µSv/h to 3.39 µSv/h, the average was 0.82 µSv/h. Apart from the tailing area, radiation dose rates ranged from 0.15 µSv/h to 0.55 µSv/h with the average value amount to 0.55 µSv/h. At the most distant point from the tailing, radiation dose rate was 0.21 µSv/h.

Analysing radon concentrations, we noticed that average annual radon concentration in the research area was 73 Bq m^{-3} whereas the average radon concentration in Poland is 6.5 Bq m^{-3} [2]. In the tailing, average annual radon concentrations ranged from 67 Bq m^{-3} to 449 Bq m^{-3}. Moreover we noted seasonal variations of radon concentrations with highest values in spring-summer seasons and the lowest during autumn-winter seasons.

Contents of eU, eTh and K in the bedrock were as follows: on the tailing: 3.8-316.9 ppm (average 69.3 ppm) U, 5.7-19.9 ppm (average 6.6 ppm) Th, 1.4-3.6% (averge 1.3%) K, apart from the tailing area: 0.8–69 ppm (average 13 ppm) U, 1.6-9.9 ppm (averge 6.6 pmm) Th, 0.9-1.9% (average 1.3%).

We observed increased radioactivity in the area of the Grzmiaca tailing and around its nearest vicinity. Moreover we noticed that not only tailing can have influence on higher radioactivity registered around tailing but also increased uranium contents in the bedrock.

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P41

RADON CONCENTRATION STUDIES ON OLD BUILDING MATERIALS

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A class of poor or local materials, frequently used in the past, are known today to be possible sources of radiological risk. This is especially true for dwellings of the central-southern part of Italy where, in particular, volcanic tuff was largely used in the past. Restoration and use of old or ancient dwellings require dedicating measurement technique of radon activity concentration especially in the phase before dwelling recovering.

To perform the measurements and to investigate possible mitigation methods we realised a closed chamber interfaced with radon detectors. We present the experimental set up and results of test on samples of old Italian building materials performed taking into account various indoor parameters as temperature, humidity and the particular use of the environment.

P42

A FURTHER STUDY OF RADON AND ITS PROGENY BEHAVIOUR IN INDOOR AIR IN PRESENCE OF ARTIFICIAL AEROSOL SOURCES

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This paper deals with a study carried out to characterize the pathway of radon progeny as a function of microclimatic parameters, particulate nature and dimensions.

The scope is to improve the knowledge of phenomena related to the unattached fraction of radon decay products, their interaction with particulates and the plate-out during the time. In particular several experiments were performed in a reference radon chamber in presence of different artificial sources of aerosol, such as tobacco cigarettes smoke, electronic cigarettes smoke and mosquito’s sticks: in these conditions the microclimatic parameters, the concentrations of radon and its progeny (in terms of PAEC) and the size distribution of aerosol and its concentration were measured.
In the present work, the results are showed and discussed.

These new results are compared with ones achieved by the authors in a previous study (1) that considered the influence of aerosol generated by burning candles and incense sticks on the radon progeny behaviour in air and on the equilibrium factor (F).

The series of tests confirmed that the introduction of an aerosol source led to a total PAEC double compared to the initial value, while the unattached fraction is drastically reduced. Furthermore in the considered conditions the interaction of RDP (Radon Decay Products) with aerosols seems to be independent from aerosol size distribution, not linear with aerosol concentration and in some circumstances related to aerosol chemical composition.

Up to now, tests on the behaviour of TDP (Thoron Decay Products) in ENEA reference chamber are not possible for technical reasons, such as very long life of TDP and the absence of a suitable thoron source, although in-field measurements performed in some old buildings showed that TPD can be more abundant than RPD.

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P43

INTERNATIONAL INTERCOMPARISON OF PASSIVE RADON DETECTORS UNDER FIELD CONDITIONS AT MARIE CURIE TUNNEL IN LURISIA (ITALY)

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In recent years many radon intercomparison exercises have been organised; mostly they took place in "radon chambers", in standard conditions of temperature, humidity and radon concentration. Many radon laboratories today appreciate the possibility to test their systems during in-situ exercises, with exposures having place in real conditions, which are less controlled and much more variable, very similar to the ones in which devices are normally exposed.

To this purpose, an intercomparison was organised in the uranium cave belonging to the Lurisia spas complex, a pristine and evocative environment in northern Italy, with natural high concentrations of uranium and radon, and which was visited also by Marie Curie in 1918.

The Intercomparison organisation started in 2013; the first announcement has been published in March 2014, in a first stage at a national level, and subsequently at the international one. The response of laboratories to this first event has been very positive: 46 participants, from 10 European Countries and from 3 non-European countries. The passive dosimeters which were exposed during the intercomparison were about 1000 devices, mostly using CR39, but also electrets and LR115.

Exposures were two and were conducted in July and August (the first exposure went on 16 days; the second for 2 days). The integrated radon exposure range for the first exercise was 6000-9000 $kBq \cdot h \cdot m^{-3}$; for the second exercise was 600–700 $kBq \cdot h \cdot m^{-3}$.

The intercomparison results will be presented during a final event, planned for 7 and 8 May 2015 in Lurisia, where some of the critical aspects related to measurements in field will be discussed.

In the present paper a synthesis of results is given, with particular attention to:

- the organisation and the timetable of the intercomparison;
- the preliminary characterisation measurements of the place;
- the data of the two exposures and the metrological aspects;
- the correlations between device type and results.

P44

METHODS OF ANALYSIS OF LONG-TERM RADON TIME SERIES

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It is well known that radon concentration in a room follows a periodical pattern, which can be explained both by meteorological parameters (e.g. temperature, wind and etc.) and by living habits (e.g. the tendency to open windows for comfortable conditions). Early the method of radon entry analysis was developed, that is based on high-resolution radon time series and allows to determine the ventilation rate corresponding inactive and active modes of room use. Usually, the dependence of radon concentration on time is described for quasi-stationary states when ventilation rate is constant. In real situations, the processes are more complex. It was shown that change of ventilation in case of opening windows or turning on mechanical ventilation can be conveniently described by the Heaviside function in a continuous form. At the same time, temporal variations in radon concentration give an opportunity to investigate the radon entry parameters and assess the factors influencing these variations in more details. We suggest to use the autocorrelation function for describing the structure of the temporal dependence from time profile of radon, while the dominant periodicities in the data are examined by means of spectral analysis. Such analysis was conducted applying long-term radon time series obtained using AlphaGUARD radon monitor. Figure 1 presents Fourier spectra (raw periodograms), showing spectral density of the radon concentration as a function of period. The spectra indicates that rime periods as follow rule the radon variations in studied dwellings: 12 hour, 1 day, 7 days. Autocorrelation function reveals importance of living habits in radon accumulation.

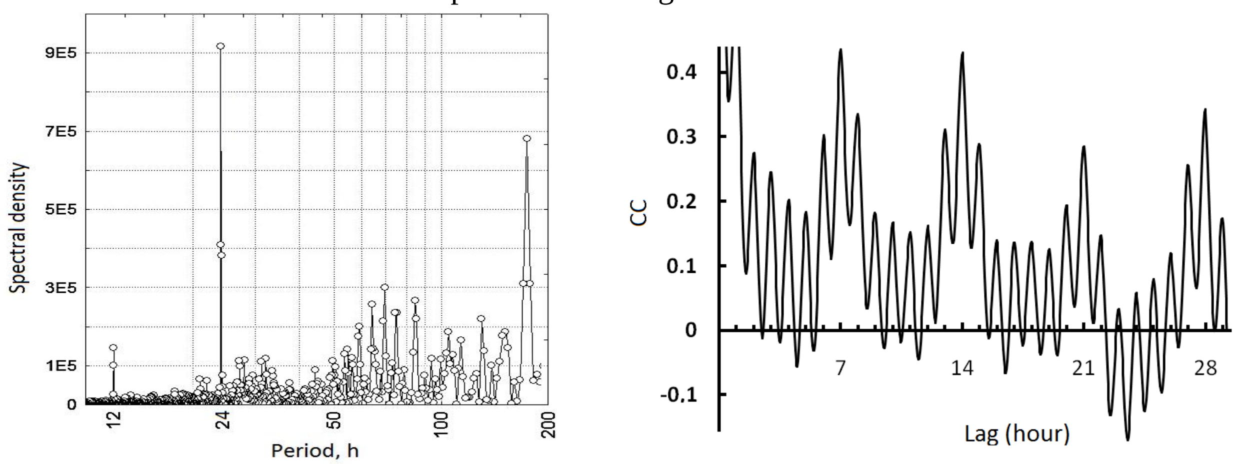

Fig. 1. Fourier spectra (left) and autocorrelation function (right) obtained from radon profile.

Thus, long-term radon time series analysis with application of well known mathematical methods provides reliable and efficient technique for revealing characteristics of radon entry, accumulation and dilution. (The study was supported by RFBR, research project No. 14-08-00677 a).

P45

EXPLORING TEMPORAL RELATIONSHIP BETWEEN SOIL ^{222}RN FLUX AND TERRESTRIAL GAMMA DOSE RATE: CASE STUDY FROM KRAKOW (SOUTHERN POLAND)

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Radon (^{222}Rn), a naturally occurring radioactive noble gas, is an excellent tracer to investigate atmospheric processes such as air mass transport and mixing in the lower atmosphere and to validate regional and global chemical transport models. It can be also used to assess emissions of major greenhouse gases (CO_2, CH_4, N_2O) and other trace volatile substances from the Earth's surface. Therefore, temporal and spatial variability of surface flux of ^{222}Rn need to be thoroughly characterized. An indirect method of quantifying spatial variability of the mean ^{222}Rn flux on the scale of the European continent was proposed by Szegvary et al. [1,2]. This approach utilizes terrestrial γ dose rate (TGDR) as a proxy of ^{222}Rn flux. Whereas satisfactory agreement between measured and predicted mean ^{222}Rn fluxes was obtained for various localities in Europe, temporal variability of surface fluxes of ^{222}Rn is still poorly constrained by TGDR data, mainly due to the fact that continuous, long-term records of ^{222}Rn exhalations rates and γ dose rate measurements, available for the same location, are scarce in Europe.

The presented work was aimed at exploring the link between temporal variability of soil ^{222}Rn flux measured in Krakow (southern Poland) between September 2005 and September 2006 and the γ dose rate measurements performed at the same location. The ^{222}Rn fluxes were quantified using two different methodologies: (i) point measurements of soil ^{222}Rn fluxes using automatic exhalation chamber system, and (ii) assessment of night-time ^{222}Rn fluxes derived from quasi-continuous measurements of atmospheric ^{222}Rn concentrations combined with sodar measurements of the nocturnal boundary layer height. The TGDR data were obtained from raw γ dose rate measurements available for permanent monitoring station of National Atomic Energy Network for Detection of Nuclear Accidents, located in Krakow, by subtracting the inherent background (self-effect), the cosmic ray component and the ^{137}Cs contribution.

The work has been partially supported by grants of the Ministry of Science and Higher Education (project nos.2256/B/P01/2007/33 and 4132/B/T02/2008/43) and the statutory funds of the AGH-University of Science and Technology.

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P46

INFLUENCE OF THE WAY OF FORMING THE DYNAMIC BALANCE IN THE RADON CHAMBER ON CALIBRATION COEFFICIENT OF THE OPEN DETECTORS

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The aim of the study was to investigate the influence of the way of forming the dynamic balance in the radon chamber on calibration coefficient of the open detectors.

There are two ways of reaching an equilibrium factor in the radon chamber: static and dynamic. The dynamic one depend on the short injections of aerosol repeated in some period of time. This method assumed that the equilibrium factor is on constant level. The static way of reaching equilibrium factor depend on the natural decrease the equilibrium factor from the set value. We have taken the average value of equilibrium factor from whole time of exposure to the calculation. The research was performed in Nofer Institute of Occupational Medicine.

We have proved that either static and dynamic methods allow to proper calculate the function of depending calibration coefficient on the of the state of the equilibrium factor in the radon chamber.

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ACCURATE MEASUREMENT OF RADON EXHALATION RATE BASED ON ERS2S INSTRUMENT

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According to incomplete statistics, there are tens of millions of tons uranium tailings produced by the world's major uranium producing countries every year. And when the uranium grade reduces, the uranium waste rock and tailing quantities will increase greatly. The radon exhalation rate measurement is a key factor in evaluating treating effects of uranium waste rocks and tailings, so the researchers widely study in the measurement of radon exhalation rate and its influence factors.

The ERS2S instrument is an electrostatic Radon / Thoron sampler for the determination of ^{222} Rn (Radon) and ^{220} Rn (Thoron) gas concentration and for the determination of the exhalation rate by the use of alpha spectroscopy. When measuring radon exhalation rate, The ERS2S instrument provides two kinds of data processing methods which are linear fitting and exponential fitting. However, in one measurement, the radon exhalation value calculated by the two fitting methods often differs greatly, which makes the workers unable to choose the more accurate radon exhalation rate.

In this paper, based on the theoretical model of linear fitting and exponential fitting methods, the applicable scope of the two methods had been studied by experiment and simulation. The results showed that the linear fitting was suitable for short time measurement. With the increase of the measuring time, the linear fitting calculation of the radon exhalation rate error will increase. If measuring time was set to 90 minutes, only when the equivalent decay constant was less than $0.15h^{-1}$, the linear fitting could be used to calculate radon exhalation rate.

Exponential fitting calculation needs more measurement data. Large error would be shown when measuring time was short and good fitting degree would be shown when measuring time was long. If exponential fitting calculation error was less than 10%, it would need at least 110 minutes measuring time with 10 minutes interval time.

Therefore, when the ERS2S instrument was used to measure a region's radon exhalation rate, it was better to conduct an experiment test in order to investigate the equivalent decay constant of the region. If the equivalent decay constant was less than $0.15h^{-1}$,the linear fitting method could be chose to calculate the radon exhalation rate, and the work efficiency could be improved.

The research results are beneficial to accurately measure radon exhalation rate using the ERS2S instrument, and also they could be the theoretical basis to study new methods for measuring radon exhalation rate.

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THE STUDY OF RADON EXHALATION RATE FROM THE BUILDING MATERIALS

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Building materials contain natural radionuclides, including α-radioactive ^{222}Rn, which can freely flow from the material in the process of exhalation. The release of the radioactive ^{222}Rn gaseous from various type materials was examined using a passive type detectors Pico-Rad with used LSC method. To characterize the rate of exhalation process mass and surface exhalation factor have been applied. Several physical factors like: porosity, permeability, moisture and temperature of the material can influence on the rate of exhalation[1,2].

In this study various types of building materials have been analyzed: such as; bricks, concrete blocks contain slag, plasterboard panel, etc.For this study special small chamber has been built. The samples were put inside with Pico-Rad detectors. In the LSC method 10 ml of scintillation cocktail classical based on a mixture of toluene with the addition of scintillator powder b-PBD (2- (4-bisfenylo) - (5-phenyl), and popop (1,4-bis-2- (5-phenyl-) benzene) have been applied. After about eight hours the measurement of pulse count rate meter was conducted by RACKBETA Wallak LS with separation α and β pulses.

Experiments were conducted in special small chamber in which the ceramics samples were placed together with Pico-Rad detectors. Each Pico-Rad vial were changed after 48 hours.
Radon exhalation coefficient obtain the highest value of 3.47 Bq/ m^2h for block foundation and 0.27 Bq / m^2h the red brick The value for the red brick in the range specified in the Guide of Building Research Institute [3] (0,11-1,40). High value of foundation block is a result of adding fly ashes portion which contain natural radionuclide of ^{226}Ra even up to 138 Bq/kg activity concentration.

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[2] Sahoo B.K., Sapra B.K., Gaware J.J., Kanse S.D., Mayya Y.S., A model to predict radon exhalation from walls to indoor air based on the exhalation from building material Samales, Science of the Total Environment 409 (2011), pp. 2635–2641
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COMPARISON OF SOME ORGANIC SCINTILLATION SOLUTIONS FOR FAST DETERMINATION OF ^{222}Rn IN DRINKING WATER SAMPLES

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The primary internal dose from ^{222}Rn in drinking water is not from ingestion but from inhalation of radon and its decay products. Most public drinking water supply has high content of ^{222}Rn. Two ingredients cocktail contain 70 % ethylobeznzene or cyklohexane and 30% Ultima Gold F can be proposed to determination of ^{222}Rn in the water with high efficient LS counting.

According to new EU regulation the value ^{222}Rn concentration in drinking water should be permanently monitored. Therefore, the fast, cheap and reasonable method for ^{222}Rn determination should be applied for these analysis. Liquid scintillation cocktail of directly ^{222}Rn extraction to the scintillation solution has been provide as a fast method for ^{222}Rn counting [1]. Particularly, the α/β separation option allows to diminish the background levels and consequently improve the detection limits. However, for these purposes the efficient extraction system should also ensure the clear distinction between α and β pulses in counting system used for liquid scintillation counting for example in BetaScout counters.

A few aromatic liquid compounds are used for extraction of ^{222}Rn from water samples [2]. The relatively high separation coefficient (~50) for such system allow to use simple ^{222}Rn extraction procedure directly in 20 ml scintillation vials containing 10 ml of insoluble in water scintillation cocktail and 10 ml of water sample. Therefore, it seems to be reasonable to check a few organic scintillation solvent to compare their ability to extract ^{222}Rn as well as to check their α/β separation possibilities. As a standard solution the toluene based scintillation cocktail has been used for comparison.

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^{222}Rn, ^{226}Ra AND ^{228}Ra ACTIVITY RATIO IN WATER SAMPLES FROM CENTRAL POLAND

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The uranium chain radionuclides are usually used for a wide range of application in the Earth Sciences. Typical uses of these environmental isotopes include the identification of source of water and solutes, determination of water flow paths, assessment of nutrients within the ecosystem, water budget. A few elements exhibit variations in their isotopic composition, resulting from radioactive decay its precursors present in the geological formations. These isotopic ratio variations can be used for rock – water interaction and applied in weathering and hydrology studies.

In this work activity ratio ^{222}Rn/^{226}Ra, as well as activity concentrations of ^{222}Rn, ^{226}Ra and ^{228}Ra were determined in selected thermal groundwater, ground and surface water samples from central Poland. ^{228}Ra was determined by gamma spectrometry after co-precipitation with MnO_2, whereas ^{222}Rn and ^{226}Ra was determined by liquid scintillation counting.

The average isotopic ratio ^{222}Rn/^{226}Ra and activity concentration of ^{222}Rn, ^{226}Ra and ^{228}Ra for different type of water sample from Poddebice and Uniejow was shown in the Table 1.

Table 1. Activity concentration of ^{222}Rn, ^{226}Ra and ^{228}Ra and ^{222}Rn/^{226}Ra isotopic ratio in different type water.

location	water type	^{222}Rn [Bq/dm^3]	^{226}Ra [mBq/dm^3]	^{228}Ra [mBq/dm^3]	^{222}Rn/^{226}Ra
Poddebice	thermal groundwater	3,32 ± 0,76	20,6 ± 7,3	38,1 ± 7,6	165 ± 41
	deep well water	6,20 ± 1,00	4,4 ± 2,0	4,5 ± 1,8	1397 ± 728
	river water	0,30 ± 0,14	2,6 ± 1,0	6,3 ± 2,0	128 ± 68
Uniejow	thermal groundwater	2,50 ± 0,97	583,0 ± 69,0	366,0 ± 54,0	4,3 ± 1,5
	river water	0,12 ± 0,06	2,6 ± 1,1	4,8 ± 1,2	47 ± 17

The observed differences in ^{222}Rn/^{226}Ra ratios and 222Rn and radium activity concentration can be used as indicator for determination of stability of the underground water reservoirs.

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INVESTIGATION OF THE INFLUENCE OF CHAMBER CONSTRUCTION PARAMETERS ON RADON EXHALATION RATE FROM SOIL

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It is well known that after radon ^{222}Rn has been produced from the decay of their parent ^{226}Ra in solid grains, a fraction of them escaped to the pore space. Exhalation of radon from soil has already been extensively studied. However, most of these studies were performed regarding the influence of meteorological and soil parameters.

As radon exhalation rate can be affected by the internal prosperities of the sample, it may be also influenced by the exhalation chamber geometry such as volume to area ratio or other construction parameters. Different accumulation chambers hooked up to RAD–7 radon monitor (Durridge, USA) have been tested together with desiccant in a closed cycle to measure radon exhalation rate and monitor meteorological conditions simultaneously. The measurements of radon exhalation rate were performed on well known testing grounds. The results obtained using different accumulation chambers set-ups and two calculations methods are discussed.

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PRELIMINARY RESULTS OF INTEGRATED RADON AND THORON MEASUREMENTS AT SNOLAB UNDERGROUND FACILITIES

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SNOLAB is an underground science laboratory specializing in neutrino and dark matter physics. Located 2 km below the surface in the Vale Creighton Mine located near Sudbury Ontario Canada, SNOLAB is an expansion of the existing facilities constructed for the Sudbury Neutrino Observatory (SNO) solar neutrino experiment with 5,000 m^2 of clean space underground for experiments.

Raduet and NRPB types integrating detectors (using CR-39) were set to ten different locations in underground. The detectors were changed and evaluated in consecutive three months periods. Our aim was to gain information about the radon/thoron levels for a whole year and see the seasonal variations. Other concern was the performance of this types of detectors under these special circumstances id est in the presence of a highly developed ventilation system and the clean laboratory environment

HIGH INDOOR RADON VARIATION INDUCED BY GEOLOGICAL FACTORS

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In this work, the correlation between indoor radon concentration and the geological and geochemical environment (i.e., rocks, soil and water) is investigated in four geologically very different regions of South-Eastern Europe.

Variation of an order of magnitude of indoor radon concentration measured in several cases in one season, compared to other seasons, is explained from a geological point of view. It is shown that such unexpected behaviour of indoor radon concentration cannot be always attributed to the outliners in the indoor radon measurement and they should be considered more carefully. One of the goals of this study is also to make qualitative investigation of the relationship between
the indoor radon concentration and the geological background, in order to outline geogenic radon prone areas.

Besides the temporal variation of indoor radon, regarding the radon mapping, the spatial indoor radon variation is also emphasized, since it is possible to have very localized area with high radon potential. Regarding the spatial variation, large differences of radon concentrations in different rooms of the same house are noted in certain cases.

The measurements were performed in time series of different durations and sometimes longer than one year. A method to estimate average annual radon concentration is presented in the case of an interrupted time series. A method of non-linear regression is proposed to estimate the annual mean concentration when one seasonal measurement is missing.