9^{th} International Conference on Protection against Radon at Home and at Work

Book of abstracts

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Organizing committee:

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9th International conference on protection against radon at home and at work – book of abstracts

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Dear Friends, dear Colleagues,

it is our great pleasure to welcome you in Prague on the occasion of the 9$^{\text{th}}$ International Conference on Protection against Radon at Home and at Work. From the very first moment of planning of this meeting it was clear to us what would be the key topic of the already ninth Prague radon conference. Recently published ICRP publication 137 – Occupational Intakes of Radionuclides: Part 3 gave us new values and new approach to dose assessment from radon and its progenies exposure; brought long discussions between scientists, regulators, lawyers and many sleepless nights to several regulators and radiation protection specialists. Conversion factor for the calculation of effective dose from inhalation of radon and its progenies brought us new challenges, mainly in the protection of workers. Moreover, measurement technique and data analysis are more advanced than ever. Dose from radon is not the only topic of the conference. Looking at the conference program there are four full days of interesting presentation on various topics connected with radon and thoron. This would be our starting point for further discussion to which we would like to invite you.

We sincerely thank to the invited speakers – Martha Palacios, Bernd Hoffmann, James Marsh and Ferid Shannoun. We also thank to the exhibitors for their support.

Peer reviewed manuscripts will be traditionally published in the Special issue of Radiation Protection Dosimetry, thus not only the participants, but the wide radon society will have a chance to see the actual state of the art.

We would like to wish you an interesting and fruitful experience during all the time spent in Prague and at the conference.

Kateřina and Lenka, organizing committee

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Protection strategy against radon in Switzerland

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The FOPH is responsible for managing the “Radon Action Plan 2012–2020”. This action plan essentially aims to adapt the Swiss protection strategy to the recent international recommendations. With the entry into force of the revised Radiological Protection Ordinance (RPO) on 1 January 2018 an important milestone of the action plan has been achieved.

The RPO specifies a reference level of 300 becquerels per cubic metre (Bq/m^3) for the concentration of radon in buildings. With the introduction of this reference level radon has become a public health problem at the national level and is no longer limited to some regions of risk. In fact, this level is exceeded in almost 10% of the 150 000 buildings that have been measured up to now. Consequently, the authorities that grant building permits for new buildings and reconstructions now have the responsibility to inform clients about the radon issue throughout Switzerland.

In the case where the reference level is found to exceed 300 Bq/m^3, it is up to the owner to take action and pay for the necessary remedial measures. The Canton reserves the right to order the remediation if the owner of the building remains inactive. The FOPH has clarified certain provisions of the RPO in the “Guidelines for Radon”, by integrating for example criteria to prioritize a measurement or a remediation.

Specific provisions require systematic measurements of radon in schools and kindergartens. If the reference level of 300 Bq/m^3 is exceeded, the responsible Canton shall order the remediation to be carried out within three years at the latest.

With regard to workers a threshold value of 1000 Bq/m^3 is applicable in addition to the reference level of 300 Bq/m^3 for the concentration of radon at the workplace. If the threshold value exceeds 1 000 Bq/m^3, the company shall determine the annual effective dose that the workers receive from radon. If this dose exceeds 10 millisieverts (mSv) per year, the company shall immediately carry out measures to reduce the dose.

At present the FOPH is preparing the new national strategy for the period after 2020.

Radon in Canada – protecting Canadians in their indoor environment

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The Canadian landscape is prone to high radon levels due to our weather, geology and tight building envelopes. In 2007 Health Canada reduced our radon guidance level, which sparked the initiation of a new industry focused on providing radon services. Since that time, the radon industry in Canada has had to learn, grow and adapt in order to develop an approach to successfully manage radon in our buildings.

This presentation will touch on unique aspects of the Canadian radon industry including techniques for radon mitigation in new construction and existing buildings and a comprehensive training and certification program to support those initiatives.

In addition we have also taken a unique approach to engaging with the Real Estate community which we all know is a valuable opportunity for information transfer with homeowners. With respect to the workforce, an ever increasing interest in the protection of occupants from radon in commercial, industrial and institutional buildings will also be addressed.

Prehistory of the Czech Radon Programme

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The Radon Programme could be started in 1958. A lot of special circumstances followed which braked or accelerate the situation. One of them and maybe the ruling one was that the area of the Czech Republic for geologists known as a Uranium Province with a lot of granite areas and later Uranium mines was under the ruling of the SSSR during years 1945–1989. Therefore the first signal of using building material with higher level of natural radioactivity in 1958 was treated as a secret event and the reuse of this material was underestimated and not examined consequestionally. Contrariwise, great research of natural radioactivity in building materials started in the 80-ties, because socialistic producers of building material cannot use wrong raw material. An important signal started measuring in Joachimstal in the late 80-ties, where Agricola as the first calls attention on Bergkrankheit of miners in the silver mines, later in the 1890-ties indicated as lung cancer. Later mining of silver changed to mining of pitchblend to produce uranium cake for production of uranium glass. High interest of Mme Curie on waste material of this factory to separate polonium and radium was not warning at that time. This waste was in Joachimstal used as building material. Extreme concentrations (some them were world extremes) of radon were found in the late 80-ties in these buildings. Of course these measurements had to be done in secret, e.g. talking inhabitants that Trabant (smoky 2-stroke engine cars from East Germany) exhalations are measured. Proposition of a Radon Programme could be ready after high radon levels were found in some buildings in granite area, but again they should remain secret. One acute problem started year before the collapse of the Soviet Union, with 3 000 owners of buildings of type START built of slag concrete with elevated concentration of ^{226}Ra. The search of a democratic and humanness solution of the radon problem started immediately with the installation of the democratic government in December 1989. Important help came from the group of owners of these START homes who were interested on repurchase or sanitation on state costs. An Interministerial Committee for radon was founded and operated for next ten years. Then the State Office of Nuclear Safety took over the responsibility for the working of the Radon Programme of the Czech Republic.

Indicators for evaluating the effectiveness of a National Radon Action Plan: necessity and examples

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Based on the experience of some countries – which had developed and adopted a National Radon Action Plan (NRAP) to plan and coordinate the several actions needed to reduce the health risks from exposure to indoor radon – the current international regulations and recommedations (i.e., the recommendations included in the 2009 WHO Handbook on radon, the Directive 2013/59/Euratom on Basic Safety Standards and the 2014 International Basic Safety Standards on Radiation Protection and Safety of Radiation Sources, sponsored by IAEA and other five international organizations) have required to develop and adopt a NRAP.

The effectiveness of an NRAP needs to be periodically evaluated, as requested for example by the European BSS, in order to verify if the specific goals are going to be obtained and, in case, to identify appropriate modifications to be introduced in the NRAP. Therefore it is necessary that a NRAP includes the identification of adequate indicators to perform such periodical verification. In general the indicators should be referred to the specific goals of a National Radon Action Plan and should be measurable. These indicators should also be feasible and sometimes this can represent a major challenge. At present, there is no already established international agreement or guideline on this issue, so that it is quite interesting to discuss this issue in an international meeting.

In this presentation, some examples of possible indicators, based on the experience and current discussion in Italy, will be presented and discussed in comparison with examples from other countries.

The new Austrian indoor radon survey – objectives, methodology, challenges and results

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In Austria, a representative population-weighted national indoor radon survey was carried out from 1994 to 2004 (ÖNRAP). As for that survey different measurement systems were used (including short term) and the number of radon measurements was low in most municipalities, it was decided – in the course of the implementation of the new EU-BSS – to conduct a new national survey. The main purpose of the new survey is to develop a data basis to delineate reliably radon priority areas. Therefore, a geographically-based survey with 6-months passive radon measurements in more than 30 000 dwellings was carried out from 2014 to 2019, province by province. The measurement points (dwellings) were selected according to defined rules (grid, geology, municipalities) among members of the voluntary fire brigade (more than 300 000 members).

In this contribution, we will present the methodology of the survey and evaluate the advantages, challenges and return rates. Furthermore, the measurements results and dependencies (geographic distribution, impact of e.g. building characteristics, geology, annual variation on the radon concentration) will be discussed. Although the survey was not designed to be representative for the Austrian population, we will test its representativeness and will compare the results with the population weighted national indoor radon survey (ÖNRAP).

Design of a national indoor radon survey for South African Homes

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Radon is a naturally occurring radioactive gas produced by the decay of radium, and is part of the normal radioactive decay chains of thorium and uranium. Since these elements are commonly found in soil, rocks and building materials, the radon gas can emanate into buildings and homes. Due to its high density, it tends to accumulate in low areas and once inhaled, an elevated radon-in-air level can cause lung cancer due to the alpha (α) particles emitted during its decay. It is thus of interest to have national data on radon levels, not only to inform but also to mitigate high levels by improving ventilation. Numerous countries have embarked on national indoor radon surveys. In 2018 the National Nuclear Regulator (NNR) of South Africa initiated a project to design a national indoor radon survey for the country. As part of this project we are actively measuring the concentration of radon in open and public spaces, homes and schools. Here we report on our results from pilot studies launched in the country, present our analysis of the data, and discuss the methodology followed.

Evaluation of representativeness of samples used for indoor radon surveys

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The estimation of the indoor radon exposure of the population of a country is generally carried out by the means of surveys designed in order to have sample representativeness as target (population-based survey). However, the estimates of radon concentration distributions could be affected by biases if sampling was not random (for example, using volunteers), if there were differences between the sampling frame and target population as well as in case the percentage of refusals to participate to the survey was not negligible.

In these cases, it is necessary to check the representativeness of the sample comparing the characteristics of the target population with those of the sample. For this aim, additional information regarding the sample is collected by the means of ad-hoc questionnaires containing the same (or comparable) questions about building and dwellings characteristics of the Census questionnaires.

This approach was used for the second Italian national survey conducted in a proxy of all the Italian dwellings considering that sampling (stratified for all the Italian Provinces) was performed from a list of houses of employees of a national telephone company.

An earlier study showed a quite good agreement between characteristics of the sample and of the general population at national level. In this work, we have extended the previous analysis to all the Italian Provinces (strata) finding that, for nearly every stratum, sampled dwellings are mostly located in the main administrative centres as compared to the other towns of the Province. Since average radon concentration in big cities is generally lower than in smaller ones, these findings could lead to underestimate the actual mean radon levels. Finally, the results of this study suggest the need to evaluate the representativeness of the sample used for radon survey at different scale levels.

Indoor radon monitoring in kindergarten facilities: a pioneering study in Brazil

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The current study presents the results of indoor radon concentrations observed in 45 public kindergarten units in the municipality of Poços de Caldas, Brazil. 342 children occupied rooms were monitored for an average of 356 days, through the installation of ATD detectors assembled in a diffusion chamber. After exposure, detectors were treated (etched) for 60 minutes under a 6.25 M sodium hydroxide solution at 98 °C. Measurements resulted in an arithmetic mean concentration of 83 Bq/m^3 and population weighted arithmetic mean of 82 Bq/m^3, presenting additionally a high range of concentration values (3–697 Bq/m^3). A geometric mean of 61 Bq/m^3 was also observed. A relationship between influence factors – such as building characteristics and ventilation habits and high concentration results – was not clearly evidenced in this study. However, indoor radon monitoring in school environments (which are pioneering in Brazil) represents an important step towards the adoption of a national radon program.

Challenges in managing radon at workplaces – status in Sweden

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Elevated radon concentrations at workplaces do occur in Sweden. The extent of the problem is gradually being mapped as a result of the implementation of the EU-directive 2013/59/Euratom. The present regulation systems include a reference level of 200 Bq/m^3 and three binding limits that take into consideration the radon concentration in an environment as well as the time spent in that environment. The regulatory limits are set for three categories of workplaces 1) workplaces located above ground, 2) furnished underground environments and 3) mines/tunnels under construction. Radiation dose is regulated indirectly through the binding limits. Radon concentrations and exposure of workers have been evaluated at several workplaces including offices and schools above ground, an iron mine, water works, a furnished tunnel and a couple of other workplaces chosen randomly in underground environments. Results show that elevated radon concentrations exceeding the reference level of 200 Bq/m^3 in working environments above ground do not necessarily imply high exposure due to forced ventilation during working hours. At water works that use groundwater as a source of drinking water, radon concentration exceeding 1 000 Bq/m^3 is not uncommon. Evaluation of effective dose for one technician at a water work however shows that 6 mSv per year is not exceeded due to the optimization principle that is applied in the form of working in shift and automation of several processes that reduces the exposure time in environments with high radon levels. The situation for underground working environments is complex. Measurement strategies vary in different underground environments and there is a need to investigate how and when radon levels should be measured so that the results are representative of the annual average concentration that workers are exposed to. In the iron mine with a well-established measurement strategy including monitoring with radon dosimeters the radon exposure was found to be very high. Hundreds of workers are exposed to high radon concentrations and some few workers are receiving dose up to 20 mSv/year. The need for optimization is necessary in such environments.

Modelling the probability of indoor radon concentration exceeding 300 Bq/m^3 – new approaches using machine learning

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Following the European Basic Safety Standards which form the framework of European Rn regulation, all EU Member States are required to delineate Rn priority areas (RPAs). In Germany, RPAs are defined as areas were at least 10% of dwellings are expected to exceed the reference level of 300 Bq/m^3.

In a first step, we will model the "indoor radon concentration (IRC) exceedance" as a function of the geogenic radon potential (GRP) since geogenic radon is the major source of indoor radon. In a second step, we will present a machine learning (ML) model for predicting the IRC exceedance as a function of multiple environmental covariables (predictors). The motivation for the implementation of more predictors is that IRC exceedance is not solely determined by the availability geogenic radon (proxy GRP) but also by factors such as building type, building material, age of the house, ventilation intensity etc. However, data for these additional drivers of IRC are not available on the national scale. The environmental co-variables implemented in the ML model may act as proxies for these additional drivers of IRC and, therefore, could improve the prediction accuracy.

In this study, we use ≈ 40 000 long-term IRC measurements across Germany in combination with multiple environmental predictors for building ML models. Potential predictors are newly calculated predictions of radon concentration in soil gas and soil gas permeability, climate data, Euclidean distance fields, geological units, soil moisture data, tectonic fault data and geomorphological parameters.

The final map of IRC exceedance is expected to have a spatial resolution of 1×1 km. The accuracy of the calculated exceedance probabilities will be validated with independent indoor radon concentration test data.

Comparison of indoor radon long-term measurement systems – “internal tender” for the national survey

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According to the Council Directive of EU 2013/59 Euratom, EU Member States shall establish a national action plan addressing long-term risks from radon exposures in dwellings. First issue that should be taken into accout when designing the action plan is developement of the strategy for conducting surveys of indoor radon concentrations for the purpose of estimating the distribution of indoor radon exposure.

Preparing for such an extensive study, several challenges should be resolved, e. g. scope and representativity of building stock being tested, survey design, and measurement systems which will be utilized. The best way for comparison of strenghts and weaknesses of pre-selected measurement systems is a pilot survey. Results of such pilot in-field test will be demonstrated.

Radiation protection activities during realization of the state program on protection of population of Zhovti Vody city

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The city of Zhovti Vody is the "capital" of the uranium mining and milling industry of Ukraine. The mining and milling of uranium has been carried out here for more than 60 years. During this time, along with the production the city grew and developed. As a result of production activities, as well as due to the human factor, the territory of the city was contaminated by radioactive rocks. These rocks have been used in the construction of private houses unknowingly. To normalize the radiation situation in the city, a targeted State Program was adopted in 2003 for a 10 years' period. In 2013, the Program was extended to 2022. In accordance with this Program, work continued on cleaning up urban territory, measuring radon isotopes in homes and conducting anti-radon repairs in rooms. The results of these works are given in the article.

Radon measurements done by school kids with DIY device – preliminary results

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With support of Copernicus Science Center and Central Laboratory for Radiological Protection in Warsaw almost 500 primary school pupils from 9 schools in Mazovia District in Poland, age 12–16, were able to measure radon activity concentration in air in chosen locations, mainly at schools and homes. Students task was to build their own etching device, build casing for Cr-39 solid state nuclear track detectors, set up microscope stand for reading etched detectors and calibrate whole system with given detectors of known reference radon exposition. We present how they manage with the tasks.

Annual variations of indoor radon concentration in workplaces: some results and implications on protocols

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The 2013/59/Euratom Council Directive has adopted the new concept of reference level (RL) which is expressed in terms of annual average activity concentration of radon in air. This definition assumes the annual average concentration as representative of the long-term average over many years. However, the estimates of this long-term average using a single annual radon concentration measurement could be affected by year-to-year variations (or annual variations) of radon concentrations in the same location. These variations, if not negligible, could have an impact on regulations.

Moreover, annual variations in workplaces could be different from those in dwellings due to changes related to working activities. For this reason, the available data on annual variation in dwellings could not be valid also for workplaces. Therefore, we performed a study aimed to evaluate annual variations in workplaces of a research institute.

Radon measurements were carried out in 120 rooms located in 23 different buildings and repeated after few years (up to 3 years). About 70% of the rooms were located at ground or lower floors. For each room, annual variation was calculated as coefficient of variation (CV) between two measurements at different years.

Results show that median CV is 16%, very close to that found for dwellings located in nearby areas. Moreover, for rooms with the first annual average higher than 200 Bq/m^3, it was found a median CV slightly higher (21%), and for 80% of these rooms, radon concentrations measured after few years was found to be decreased, with an average reduction of about 30%.

In this work, the likely explanations of these results as well as their possible implications on radon protocols will be discussed.

Radon in the workplace – regulatory framework in the Czech Republic

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Radiation protection in the workplace with natural sources of ionizing radiation in the Czech Republic is defined by Act No. 263/2016 Coll., The Atomic Act. This Act introduced some new concepts and requirements regarding radiation from radon in the workplace (§ 96 and 97 of the Atomic Act). Details are set out in § 92 to 95 Decree No. 422/2016 Coll., On Radiation Protection and the Security of Radionuclide Source. Workplace with radon is classified as existing exposure situation. The legislation set a reference level of 300 Bq/m^3 for the average concentration of radon activity in the workplace, with a working time of 2 000 hours in 12 months.

For workplace with potentially increased exposure to radon include are considered, according to § 96

a) underground workplace,

b) workplace in which water from an underground source is pumped, collected or otherwise similarly handled, in particular pumping stations, spa facilities, bottling facilities, water treatment facilities,

c) workplace located in the underground or first floor of a building that meets the conditions set out in the Decree in § 92 and in Annex 25.

Anyone who performs activities involving the operation of a workplace with potentially increased exposure to radon shall

1. report to the Office information about the workplace,
2. ensure measurements to establish the effective doses to workers in the workplace
3. ensure optimisation of radiation protection, if the measurements demonstrate that the reference level of 300 Bq/m^3 have been exceeded
4. inform workers about the potentially increased exposure to radon, about the results of the measurements, effective doses and the related health detriments following exposure, and, where appropriate, on the measures taken to reduce exposure to radon.

If the worker's exposure in the workplace could exceed an effective dose of 6 mSv per year, it is considered to be the workplace with higher exposure to radon according to § 97 and more stringent requirements are imposed.

Mapping and monitoring of indoor radon studies within Ghana Atomic Energy Commission and residential communities

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Radon is acknowledge as leading cause of lung cancer apart from Smoking cigarette. Other countries and agencies including WHO also reported that, it is a major cause of lung cancer, therefore, early detection is essential. Indoor radon concentration in buildings have not yet been evaluated in Ghana but most studies done have focused on water and soil with few done on indoor radon. At the present time, Ghana does not have national guidelines specifying the acceptable radon levels in both workplaces and dwellings but have been using international action levels and limits. The studies of indoor radon in workplaces were to determine whether there exist any significant indoor radon levels. The CR-39 were exposed between June–August, December–February and March–May. The Exposed, CR-39 radon detectors were sent to Regional Agency for Environmental Protection of Friuli Venzia Giulia (ARPA-FVG), Udine, Italy for the analysis. The detectors were etched and latent tracks formed were counted in 144 fields using an optical microscope of 40× magnification objective lens. The tracks density left on track films were then used to evaluate the indoor radon concentration. The average for offices (169.5 Bq/m^3), laboratories (188.5 Bq/m^3), bedrooms (48.9 Bq/m^3), halls (36.3 Bq/m^3). Radon concentration in the offices and the laboratories of GAEC were higher than residential dwellings. The average indoor radon concentrations for the buildings were found to range from 19.3–558.7 Bq/m^3. The results were compared with similar studies done in Ghana. The buildings recorded 30.3% of indoor radon concentration greater than action levels proposed by WHO, indicating that not all the buildings in studied areas are negligible.

Teaching radon and environmental radioactivity; an experience in the frame of an Erasmus+ European partnership

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Seven universities are involved in a two-year European Erasmus+ partnership, which topic is Train the trainees-train future trainers in radiation protection and nuclear technology. In this frame, training schools are organized regarding different fields, including environmental radioactivity. This academic year, a one-week training school was organized by HE2B-ISIB (Brussels) and UHasselt (Diepenbeek) in Brussels. Fifteen students from different countries worked together and were confronted with possible problems regarding radioactivity in our environment. For example, radon or NORM were taken into consideration and the students had the opportunity to work on these materials on the field and in the laboratory. The learning outcomes were numerous such as awareness and explanation of problems regarding radioactivity in our environment, measurement of environmental radioactivity on site and in the laboratory, evaluation of what is harmful and what is inevitable in accordance with ALARA. But the students had also to develop training skills like explaining a laboratory task to the other groups to train them. The training school of the second year will be organized in March by UBI (Universidade da Beira Interior) and will focus more on the teaching skills. The students will have to make different audiences like pupils, secondary school or university students, aware of issues regarding radioactivity in the daily life. Different tools will be used to achieve this result, such as experiments, videos, role-plays, ...

The performance of European calibration services concerning radon in air

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As regards protection against radon exposure (^{222}Rn) at home and at work, the transposition into national law of European Council Directive 2013/59/EURATOM requires a reliable metrological basis ensuring confidence in the measurements. In the framework of the EMPIR research project Metrology for Radon, an intercomparison is being conducted to validate the calibration performance of European radon calibration facilities.

Although the comparison is open for each radon calibration service, the focus is preferably on services that represent the respective national reference for the quantity radon activity concentration in the air.

The German Federal Office for Radiation Protection (BfS) provides an electronic radon instrument ALPHAGUARD (PQ 2000) as transfer comparison device for the intercomparison. The device is sent to the participating laboratory to perform the exposures at 3 different levels: 400, 1 000 and 6 000 Bq/m^3. After the exposures have been made, the device must be returned to BfS. This procedure is repeated one after the other for each of the participating laboratories. In the meantime, when the device is at BfS, the proper operation of the device and its compliance with metrological requirements is checked.

A total of 14 laboratories expressed their interest in participating. The comparison is currently being finalized and the results evaluated. The course of the interlaboratory comparison as well as first results on the performance of European calibration services will be presented.

Results from the three-month comparison of electronic radon integrating detectors with passive etch track detectors

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Etch-track detectors have been identified as the most suitable cost effective technique for estimating the annual average radon concentration in dwellings. Recently, numerous Electronic Radon Integrating Detectors (ERID) have gained popularity due to their relatively low cost and ease of use. The performance and ability of these types of detectors to determine accurately the long-term average radon concentration has been examined in this study.

Eight types of ERID were exposed side by side with passive etch-track detectors in the Public Health England (PHE) radon chamber for up to 3 months in a known radon atmosphere. Thirty different detectors were included in this study: ten Canary, five Ramon, two Sun Nuclear 1027, two AlphaE, two Corentium Pro, three AER+, three Radon Scout and two Wave. The performance of instruments was compared with results of the PHE passive radon detectors.

At the beginning of the study, the background of the ERID instruments was obtained by placing them in a radon-free atmosphere. The detectors were then placed in the PHE radon chamber, which is constantly monitored, and the radon concentration from each ERID read on a weekly basis.

A difference in radon concentrations recorded by the devices from the same manufacturer has been identified. In addition, the records of the radon concentrations from the eight models have been compared with the reference radon levels in the chamber.

The results from the first 3 months will be presented and discussed.

Spatial variability of indoor radon concentration in schools: implications on radon measurement protocols

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The requirements about radon measurements in schools and public buildings included in most of the national and international legislations are generally restricted to all the occupied rooms located at ground floor and basement, assuming the soil beneath the building as the main source of indoor radon.

In order to assess the quality of such assumption, a study was performed in the framework of a survey carried out in 82 buildings (mostly schools and kindergartens) located in 15 Municipalities of Republic of Srpska. Annual radon concentrations have been measured in 185 rooms, some of them (45) located at first floor.

Preliminary results of this study show that in 25% of buildings with more than one floor monitored, average radon concentration was higher at first floor than at ground floor. As expected, variability among rooms on the same floor is higher at ground floor (median $CV = 22\%$) than at first floor (median $CV = 14\%$). Even if most of the rooms exceeding 300 Bq/m^3 (the maximum reference level established by 2013/59/Euratom Directive) were located at ground floor (30 out of 32), in one building an exceedance was found at first floor only.

These results, if confirmed by further studies, would suggest including in measurement protocols also requirements for rooms located at upper floors: in fact, in some multi-storey buildings, the stack effect and the contribution of building materials may lead to high radon levels also (and sometimes only) at floors not in direct contact with the soil.

Particle size distribution of radon progeny determined on the basis of ambient aerosols size distributions

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In the work were compared particle size distributions obtained using two different methods. First, by Radon Progeny Particle Size Spectrometer (RPPSS), second by Aerodynamic Particle Sizer (APS) spectrometer and the Scanning Mobility Particle Sizer Spectrometer (SMPS).

RPPSS allows receive the distribution of PAEC in the particle size range from 0.6 nm to 2494 nm, based on their activity measured on 8 stages composed of impaction plates or diffusion screens. Second method based on the measurement of the ambient airborne particle size distribution in the range from a few nanometres to about 20 micrometres using Aerodynamic Particle Sizer (APS) spectrometer and the Scanning Mobility Particle Sizer Spectrometer (SMPS). Size distribution of radioactive aerosols were determined based on the relationship between the attachment rate X of the unattached short-lived decay products which depends on the attachment coefficient $\beta(dp)$ and the number size distribution of ambient aerosols $Z'(dp)$. Based on this relationship and measurements results the probability of the generation of radioactive aerosols, dose conversion factors (DCF) for the occupational hazard and for the general population were estimated.

Measurements were performed in laboratory conditions in radon chamber with a large volume 17 m^3, radon atmosphere in the chamber was obtain using ^{226}Ra open source. To ensure different kinds of size distributions of ambient aerosols different types of ambient aerosols were generated.

Analysis by scanner of tracks produced by radon alpha particles in CR39 detectors

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The most used passive detectors for Radon measurement are the CR39s, both for the good stability of the material and for the practicality of use. But, commercial reading systems are expensive and not always fast. The aim of the present work was the development of a method for a rapid, efficient and economic evaluation of the result of the indoor Radon measurement performed with CR39 detectors. The analysis and acquisition of detector images were performed using an Epson Perfection V800 Photo scanner and the free ImageJ software. To this end, several groups of CR-39 detectors were exposed in the Radon Camera, developed and analyzed, and the image acquisition parameters of the detectors were set on the Epson software associated with the scanner. The software allows you to perform multiple acquisition of 28 detectors whose images are saved in separate files. A calibration curve was obtained in a wide range of exposure values (300–12 000 kBq h/m^3) to allow the procedure to be applied in all possible measurement environments. Furthermore, a large statistical study was carried out on the shape and size of nuclear tracks after chemical development. The dependence of the track dimensions on Radon exposure was obtained up to exposure values that lead to the start of the trace saturation effect. In conclusion, the tracks analysis methodology by scanner is effective and has also been used in inter-comparison participation and has provided good results.

Thoron interference in radon measurements for different radon monitors: results and proposal for an estimation method

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Several continuous radon monitors (CRM), including some recent and affordable ones, are available on the market. Performance of such detectors (e.g., accuracy, linearity of instrument response and influence of different climatic parameters) are generally evaluated by means of intercomparisons carried out in controlled conditions inside radon chambers.

Some of these tests addressed also the influence of thoron (the so-called thoron interference) on the response of CRMs. As expected, they found that detectors capable of performing alpha spectrometry of radon daughters are generally less affected by thoron interference than those relying on a detection unit without energy discrimination.

However, during such studies monitors are exposed in thoron chambers with very low concentration of radon, so the results can not be extended to the estimation of thoron impact on CRMs-measured radon concentration in typical indoor environments (where radon and thoron coexist). For this reason, several experiments have been carried out in a room where both radon and thoron (near the walls) are expected to occur at medium-high concentrations.

The responses of 4 commercial CRMs (AlphaGUARD PQ2000PRO, AlphaGUARD D50, RadonEye+, and TERA TSR2) have been studied. Thoron has been contemporary evaluated by two different active monitors: i) RAD7 that relies on silicon-based alpha spectrometry; ii) AlphaGUARD DF2000 that uses a combined protocol (diffusion and flow mode) to assess thoron concentration.

Other likely interference sources have been considered and discriminated.

In addition to the thoron interference evaluations, we developed and applied an indirect method to measure thoron concentration with the tested 4 CRMs by using, for each type of monitor, a pair of detectors: one placed near the wall and one at the center of the room, where thoron is expected to be negligible. Results have been compared to those from thoron direct measurements by RAD7 and AlphaGUARD DF2000.

Determination of the thoron emanation coefficient for natural materials by means of various detectors

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Thoron (^{220}Rn) is a naturally occurring radioactive gas. Due to a short half-life 55.6 s and small amount in the environment, its share in the absorbed radiation dose is often neglected. However, in areas rich in thorium (^{232}Th), the radiation dose from the thoron can be much larger and quite significant. Therefore, it is important to develop an appropriate universal technique that allows to determine the thoron emanation coefficient.

S. D. Kanse has developed a powder sandwich technique to determine thoron emanation factor. This method is based on a closed loop system, in which thoron is pushed out by means of a flow system from the sample and measured by a detector. To check whether the used technique is universal, three different detectors were used for measurements: AlphaGuard DF2000, Sarad EQF 3200, RAD7.

A sample of the material is placed between 2 filters in the sandwich geometry. Using this technique, it is important to determine the concentration of the ^{232}Th, which was carried out using gamma spectroscopy (HPGe detector). The ^{232}Th activity were (S-sample number): S1: 11013 ± 165 Bq/kg, S2: 11994 ± 178 Bq/kg, S3: 12604 ± 189 Bq/kg, S4: 12421 ± 186 Bq/kg, S5: 15666 ± 235 Bq/kg, S6: 24379 ± 366 Bq/kg, Tuffo di riano: 200.2 ± 6.08 Bq/kg, Tuffo di Gallese: 315.45 ± 11.8 Bq/kg.

The emanation factor calculated on the basis of the results obtained from the experiment was:

AlphaGuard DF2000: S1: $0.002 \pm 4 \cdot 10^{-4}$, S2: 0.002 ± 10^{-4}, S3: $0.002 \pm 2 \cdot 10^{-4}$, S4: $0.002 \pm 3 \cdot 10^{-4}$, S5: $0.002 \pm 2 \cdot 10^{-4}$, S6: $0.001 \pm 2 \cdot 10^{-4}$, Tuffo di riano: 0.3 ± 0.05; Tuffo di Gallese: 0.19 ± 0.03.

Sarad EQF 3200: S1: $0.001 \pm 3.41 \cdot 10^{-5}$, S4: $0.001 \pm 1.5 \cdot 10^{-4}$, S5: $0.001 \pm 1.35 \cdot 10^{-4}$, S6: $0.001 \pm 8 \cdot 10^{-5}$, Tuffo di riano: 0.3 ± 0.03; Tuffo di Gallese: 0.15 ± 0.03.

RAD7 Tuffo di riano: 0.24 ± 0.06; Tuffo di Gallese: 0.17 ± 0.02.

Low radon cleanroom

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The need to achieve ultra-low radon concentration in air was realizes only recently due to the necessity to suppress radioactivity caused by the presence of radon in the air (e.g. the study of behaviour of cells or DNA in the radiation free environment, or the study of the influence of "single event effect" caused by alpha particles from radon decay product contamination in nanoelectronics). The demand for radon concentrations in air in such special cases should be at the level of mBq/m^3 and radon decay products below μBq/m^3. In addition, there may be a request for such spaces to comply with the requirements for minimum aerosol concentrations according to the ISO standard (so-called cleanrooms). State of art in radon corrective measures in buildings represents radon concentration reduction typically by factor of 10. However, since the radon concentrations in buildings are at tens and hundreds of Bq/m^3 and in the outdoor atmosphere of tens of Bq/m^3, to achieve indoor air radon concentration on the level of mBq/m^3 requires special system able to reduce radon concentration by factor more than 1 000 times in comparison to the standard environment. Such system for creating and maintaining radon-free and aerosol-free cleanrooms were built at SURO and at the underground laboratory LSM (Modane). Both systems are based on a set of 5 rooms arranged in a row from dressing room to ultra clean room. Rooms are built from specially sealed sandwich metal panels with thermal insulation. Into the last room with highest class of cleanliness (ISO 5) is delivered the radon-free air from antiradon facility delivering 20 m^3/h or 150 m^3/h, respectively. The rooms are also intensively filtered by HEPA filtration system with filtration rate of 8 000 m^3/h. For control of low radon concentration is used continuous radon monitor with sensitivity of mBq/m^3 developed by IEAP CTU. The effect of human body radon exhalation and its contribution to indoor radon was analysed.

The NRPI low level continuous radon gas monitor for measurement below 1 Bq/m^3

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In order to reduce minimum detectable activity (MDA) of any measured α, β radioactive sample as low as possible the most worldwide laboratories and research centers need to ensure also very low concentration of radon gas in ambient air. Since activity concentration of atmospheric radon gas ranging from a several Bq/m^3 to a several tens of Bq/m^3 there are required radon gas measurement instruments being able to measure its activity concentration deeply below 1 Bq/m^3 for control of efficiency of any used radon gas suppression technology.

Both a continuous alpha spectrometric radon gas monitor newly developed at the NRPI allowing measurement of atmospheric radon gas activity concentration with MDA lower than 0.2 Bq/m^3 being adjusted on an hourly basis, its calibration and a radon gas suppression technology used at the NRPI will be introduced.

Validation method for the determination of ^{226}Ra in water samples using plastic track detectors CR-39

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In this paper a validation method for the determination of ^{226}Ra in water samples, using plastic track detectors CR-39 has been studied, when, of alpha particles from ^{226}Ra in equilibrium with ^{222}Rn in precipitates collected on a filter. The precipitates were prepared from environmental water samples by collection of radium with lead nitrate as for as Pb/RaSO$_4$. The minimum detection limit of this method was 2 mBq/L, where the relative slandered division of repeatability was 4.53%, while the relative slandered division of intermediate precision was 0.06%. Linearity studying showed a correlation factor of $R^2 = 0.9976$, which is related to the strength bonding between the different elements of an excellent measure. The recovery efficiency was of this method 92.79%, and a relative error of 1.39%.

Furtheremore, this method was tested on water samples from the city of Damascus and its countryside, and urine samples of workers in the oil and phosphate industry. Results were compered with Alpha spectrometry results and they were within the limits of uncertainty between the two methodsand satisfactory.

Experience from radiation surveys (studies) in high radon areas

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Localization of gamma-ray anomalies could play important role in environmental studies. The knowledge of these size-limited areas with elevated gamma dose rate in comparison with their surroundings can provide useful information concerning the possible radiation burden of residents.

The methodology for radiation anomaly monitoring, results of in-field measurements, and indoor radon levels found in municipalities placed in the affected inhabited area will be presented.

Quality control in continuous radon monitoring and dose assessment variability in a tourist cave

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Continuous radon concentration monitoring in underground environments has an added difficulty due to the high relative humidity. It can modify the detection efficiency in electrostatic radon progeny collection systems. Radon measurements are carried on continuously in the Altamira Cave (northern Spain) with active monitors (Radon Scout), which provide radon concentration at 1-hour intervals, and also with solid-state nuclear tracks detectors (CR-39). Each radon monitor is calibrated and verified every six months in the LaRUC radon chamber (Laboratory of Environmental Radioactivity, University of Cantabria), using a reference device calibrated in BfS (Bundesamt für Strahlenschutzwith) with traceability to the PTB (Physikalisch Technische Bundesanstalt) ^{222}Rn primary standards. This work describes the main protocols and procedures for quality control of radon measurement focused to a tourist cave environment, characterized by high levels of humidity in the air and the variability of aerosol particles concentration. As an illustration of the main factors that affect the variability of the doses received by inhalation of radon in this type of atmosphere, different approximations to the dose estimation are presented.

Unattached ^{212}Pb fraction in the worker's breathing zone at high thoron concentrations

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Classical aerosol physics predicts that it is impossible to observe noticeable values of the unattached fraction of the decay products of thoron at typical concentrations of aerosol particles. The experiments, conducted in test chamber, demonstrated, that unattached fraction of thoron progeny can be observed only at low aerosol concentrations $Z < 1000$ cm^{-3} (Cheng et al., 2000). However, in some cases the theory is not consistent with field measurements. During many years, our measurements have shown that the unattached fraction of the thoron decay products in the monazite storage facility is 0.27 ± 0.13. The cause of this effect is a local increase in air exchange near the inlet of the sampling device. As a result, the unattached fraction of ^{212}Pb, which is continuously formed near the sampling point during the decay of thoron, does not have time to interact with aerosol particles. Therefore, a dynamic equilibrium shift occurs between the unattached ^{212}Pb fraction and the fraction attached to the aerosol particles near the inlet of the sampler. With the participation of a volunteer, a special experiment was conducted, when aerosol samples were taken on a system that simulates the human respiratory tract. It was found that a dynamic shift between the unattached and attached thoron fraction is also observed in the worker's breathing zone. The ^{212}Pb unattached fraction in worker's breathing zone is ≈ 0.4. It demonstrates that when evaluating inhalation exposure to the products of the decay of thoron, it is necessary to take into account the increase of the ^{212}Pb unattached fraction in the worker's breathing zone. This is important because the dose coefficients for the unattached fraction of the thoron are 6 times higher compared to the aerosol fraction.

Measurement of radon concentration in thermal spa – case study

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The first measurements of radon concentration done back in 2007 showed elevated radon concentration in basement and first floor of the main building of thermal spa located in northern part of the Czech Republic. Several measurement campaigns were carried out to seek the source of radon from which soil gas and also thermal water were proved. Under specific conditions, the radon levels reached up to several thousands of Bq/m^3 at the workplace in basement. Optimization of water filling procedure, i.e. not spraying but slow pouring, and forced ventilation were applied to reduce the radon concentration successfully. High radon levels were accidentally found in the first floor during the verification measurement of applied mitigation. The case study summarizes collected data and so far lessons learned.

The equipment for testing of measuring devices at the low-level radon activity concentration

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The National Institute for Nuclear, Biological, and Chemical protection has developed under the European project 16ENV10 MetroRADON (European metrology program for innovation and research, EMPIR) the unique equipment for testing of devices at low-level radon activity concentration. The equipment consists of airtight Low-Level Radon Chamber (LLRCH) with an inner volume of 324 liters; flow-through source of ^{222}Rn type RF 5 with activity 4.955 kBq of ^{226}Ra which was also developed within the mentioned project by Czech Metrological Institute; and the air pressure bottle as the source of air free from the radon. The mass flow controller of type Bronkhorst EL-Flow is the part of the apparatus and ensures the requested air flow through the radon source to the chamber. The homogeneity of the inner atmosphere in the chamber is ensured by the help of the continuously regulated fan which allows setting up of air flow in the range from 0.1 m/s to 3.5 m/s. The component of the chamber is among other the measuring device of climatic conditions for measuring temperature, air pressure, and relative humidity.

The construction of the equipment allows the maintaining of time stable radon activity concentration on the precise level for several days. It is possible to arbitrarily and continuously set up values of radon concentration in the range from 100 Bq/m^3 to 300 Bq/m^3.

Continuous radon-in-water monitoring

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The extraction of dissolved radon from water to gas in the most common way to measure radon concentration in water continuously. The response delay of continuous radon-in-water detection system (continuous monitor + equilibrator) is influenced by the response time of the continuous monitor and a rate of an establishment of equilibrium in the equilibrator (exchanger unit). Two types of equilibrators were used in performed experiments to compare the response time of various detection systems – RAD AQUA that uses water spraying and equilibrator with ACCUREL® PP membrane that enables radon diffusion. Each of these was connected to the continuous monitor RAD7 or RM-3. The response delay after turning on the water flow through the equilibrator was determined. The fastest detection system was RAD7 + RAD AQUA that was subsequently tested during the in-situ measurement of thermal water in the healing spa and water sources near Cheb and České Budějovice.

Attachment rate for different aerosol sources

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The attachment process is diffusion controlled under consideration of electrostatic forces and gas kinetic laws as described by Porstendörfer, 1994. This work presents a comparison of the attachment rate (X, h^{-1}) of the radioactive radon decay products to aerosols generated with different sources. Attachment rate depending on particles diameter (5 nm–20 µm) is considered and explained. Seven different sources of aerosols used in everyday life were investigated: regular and electronic cigarettes, smoking incense, candles, spirals for protection against insects, etc. The aerosol particle concentration during the experiments was in the range from 200 to 2×10^5 cm^{-3}. The number, mass, and specific surface area aerosol size distributions were measured by a diffusion aerosol spectrometer (DAS) Model 2702 M in the range from 5 nm to 15 µm. The dependence of attachment rate on particles diameter is described and presented for each aerosol source. This relationship must be sufficiently close to the activity size distribution of the radon decay products.

Indoor radon concentrations for the South African West Coast Peninsula: Vredenburg and Saldanha

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Granite commonly contains high concentrations of uranium, with subsequent high exhalation of radon gas. The geology of the West Coast Peninsula of South Africa is dominated by granite. No measurements of radon gas has however been undertaken in, or near the towns of the peninsula. A recent article predicted potentially high indoor radon concentrations in the two largest settlements on the West Coast Peninsula, the towns of Vredenburg and Saldanha, due to the granite geology. This research sets out to measure the indoor radon concentration for these towns. Measurements were first conducted during the warmer months with houses typically being more open due to the warm weather. The average indoor radon concentration of Vredenburg was found to be 30% higher than that of Saldanha, with 57.7 Bq/m^3 and 40.3 Bq/m^3 respectively. The measurements were then repeated for the colder months, which showed an increase in the average radon concentration to 153 Bq/m^3 for Vredenburg and 172.5 Bq/m^3 for Saldanha. The granite geology and lifestyle of occupants during the colder months thus seem to contribute towards elevated levels of indoor radon concentrations.

Soil radon flux measurements under activated pressure gradient

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Common methods of the radon flux measurements are of limited applicability for estimating local geogenic radon potential at the building sites due to disregarding potential advection transport. The failure to take into account the reaction of the geological environment to pressure differences created after building construction results in inability to convert from estimations of pure diffusion radon transport to the indoor radon concentration. The proposed method for estimating the radon potential of a site is based on the depressurization in accumulation chamber and monitoring of radon accumulation curve with 10 min resolution. The depressurization activates the advective transport in a porous media and determines the increase of radon concentration. In all experiments, the activation of advection has elevated the radon flux from soil compared to that under the absence of pressure difference. The method for assessing the radon potential of a site using depressurized accumulation chamber has the following advantages: two main mechanisms of radon transport – diffusion and advection, are taken into account, the survey can be carried out before the construction of a building, results of measurements make it possible to predict the radon concentration in the existing building considering actual construction features, the measured value is radon concentration in the accumulation chamber, for which the metrological system exists.

Quality assurance on indoor radon monitoring: assessment of detection limit estimation approaches

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Direct association between chronic exposure to radon gas and lung cancer comes as a result of decades of studies. Today 3 to 14% of the global incidence of the disease is attributed to the inhalation of radon and daughters as implementation of public exposure control actions is highly recommended the WHO, IAEA and ICRP. Radon measurement techniques must be robust and accessible for the conduction of monitoring programs and method validation as well as the study of performance parameters come as essential quality assurance tools. The purpose of this work is to study the parameter of detection limit (LOD) of a Solid State Nuclear Track Detector technique of indoor radon concentration evaluation. Selection of the best LOD method based on a comparison among 3 estimation approaches and their responses was proposed. The first two were both based on the Currie method, but differing in source of radon concentration data (one from proficiency testing while the other from the radon analysis system supplier). The third approach applied the BSI ISO 11665 – Measurement of radioactivity in the environment – Air: radon. The Currie estimation method, in which data from a proficiency test were considered in the form of standard deviation) resulted in an LOD of 19 kBq/m^{3}h (2 Bq/m^3 for 1-year exposure). In a second moment the same approach took into account, alternatively, a standard deviation value provided by the radon analysis system supplier, resulting in 26 kBq/m^{3}h (3 Bq/m^3 for 1-year). The approach using ISO 11665 for LOD estimation produced a value of 51 kBq/m^{3}h (6 Bq/m^3 for 1-year). The results indicate no significant difference among them in terms of yearly exposure, as any value within the range of 2–6 Bq/m^3 represents a sufficiently low risk when it come to radon. The ISO 11665 method of LOD estimation was established as the best fit for its purpose based on a conservative viewpoint, which considers the highest LOD found in the comparative study; conformity to supplier indication and the method's complexity, which recognizes a greater number of variables. The most robust and well-founded approach of LOD determination was selected in the quest for method consistency – a vital aspect for national radon programs or other large scale assessments.

Comparative measurement uncertainty study of solid state nuclear track detectors

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Analytical excellence is a continuous challenge which nuclear and radiation field institutions must take on to respond to society's needs in reliable ways. Measurement uncertainty is one of the most important quality parameters of a quantitative result, as it assesses method performance and steadiness. Nuclear track analysis techniques, which are frequently subject to relatively high uncertainty values (such as in case of low indoor radon concentrations), benefit from studies that explore the best, fit to purpose approaches for uncertainty estimation. Analytical excellence is a continuous challenge which nuclear and radiation field institutions must take on to respond to society's needs in reliable ways. Measurement uncertainty is one of the most important quality parameters of a quantitative result, as it assesses method performance and steadiness. Nuclear track analysis techniques, which are frequently subject to relatively high uncertainty values (such as in case of low indoor radon concentrations), benefit from studies that explore the best, fit to purpose approaches for uncertainty estimation. In a exercise that considered 5 ranges of integrated radon exposure within 100 and 2 500 kBq/m^{3}h, the Student's T-test applied to each range group of data indicated no statistically significant difference between the automatic and manually checked sets of uncertainty values for the intermediate ranges, while the lowest (background values) and highest concentrations presented mean inconsistency between the two approaches. The overall high %CV estimation of the automatically produced values pointed to an unexpectedly low precision (both absolutely and comparatively), calling for closer attention to automatic estimation of this parameter, especially on high radon concentrations (over 2 000 kBq/m^{3}h) and very low ones, under 100 kBq/m^{3}h. Such observations shall prompt further studies on management of satisfactory levels of reliability on automated production of results. Quality control is not be limited to a single assessment, as this approach validation should become an integral aspect of the process as a way to achieve and maintain stability and analytical consistency in the laboratory.

Measurement at NORM workplaces – preliminary results

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According to the Council Directive of EU 2013/59 Euratom, which is implemented by the Act. 263/2016 Coll., the positive list of NORM workplaces newly includes the boiler maintenance. There was no or limited experience with the dose assessment for workers working on boiler maintenance in the Czech Republic. Poster summarizes results of measurement done during last two years.

Radon inhalation experiments to test radon exhalation kinetics

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In the paper results of radon inhalation experiments are summarized that were carried out with a volunteer to test the kinetics of the ^{222}Rn exhalation from the human body after a short-time exposure to an elevated ^{222}Rn air concentration. The main goal of the study was to estimate the role of radon exhalation from the body of a person entering the radon free cleanroom. The volunteer was for relatively short time exposed in precisely measured elevated radon concentration in air (above 100 kBq/m^3). After the exposure, the time course of radon concentrations in air exhaled by the volunteer were measured and analysed in single breathes. Supplementary to the exhalation experiment, changes of ^{222}Rn decay products activities in the volunteer's body were measured by whole body counting. In the total radon exhalation from the body the exhalation from lungs dominates. Exhaled activities were compared with the prediction of the latest ICRP biokinetic model for radon. Radon concentrations in air exhaled from lungs quickly changes after the end of exposure and could be described by sum of exponential curves with first very rapid part.

It was shown, that exhalation from human body could play important role in contribution and balance of radon concentration in a radon-free cleanroom and should be taken into account in the cleanroom activities with the presence of a man. However, a rapid decrease in radon concentration in exhaled air during the first 10 minutes allows to solve the problem. The person should be placed in a temporary radon free space before entry into the special radon-free cleanroom.

Development of the secondary standard ^{222}Rn in the air at SMU

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Slovak Institute of Metrology (SMU) received in 2016 a funding for the realization of a secondary standard of ^{222}Rn in air. As a one part of the project, this standard will serve to provide traceability for laboratories that deal with ^{222}Rn measurements in environmental samples. The secondary standard consists of two main parts, a radon chamber and an electronic measurement device. The chamber is a horizontal cylinder made from stainless steel with a diameter 0.8 m, length of 2.0 m and a sheet thickness of 5.0 mm. The inner volume of the chamber is about 1.0 m^3. Considering the construction of the chamber, it is possible to test the devices directly placing them into the chamber in the radon atmosphere. The chamber stands on a mobile chassis. The chamber is connected to a ^{222}Rn source, air extraction system and other instruments by a vacuum KF system and special hoses on the top and on the back cap of the chamber for monitoring the radon atmosphere parameters.

During the development of the radon chamber the determination of its basic technical parameters, such as the exact determination of the container volume and the area of the inner walls of the radon chamber, tightness tests of the chamber and the definition of homogeneous radon atmosphere parameters were realized. This work presents technical parameters of the standard and some preliminary results of first measurements realized on the standard and some basic information about participation on two inter-comparison within the EURAMET EMPIR Project Metrology for Radon Monitoring.

This work was supported by the Slovak Research and Development Agency under the contract No. APVV-15-0017.

Radon progeny equilibrium shift at different aerosol concentration

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The influence of aerosol particle concentration on the activity of short-lived radon decay products was investigated inside standard radon chamber. Activity of short-lived radon decay products and Equilibrium equivalent concentration, EEC, of short-lived radon products were calculated by Thomas technique. The ^{218}Po:^{214}Pb:^{214}Bi activity ratio was determined for unattached and attached fraction of radon decay products at different aerosol concentrations. For unattached fraction this ratio was 1:0.31:0.06 and for attached aerosol fraction the activity ratio was 1:1.4:0.91 at low aerosol concentration (2 k cm^{-3}) and with unattached fraction $fp = 0.45$. In this case, there is no additional aerosol in the standard radon box and the equilibrium shift ratio for the total activity (attached and unattached) 1:0.55:0.27 for ^{218}Po:^{214}Pb:^{214}Bi. When the aerosol injected the unattached fraction nearly disappear at high aerosol concentration (80–90 k cm^{-3}). The equilibrium shift ratio for the total activity at high aerosol concentration 1:2:1.5 for ^{218}Po:^{214}Pb:^{214}Bi. This ratio the same for attached fraction. For unattached fraction no more 0.01 this ratio is 1:0.85:0.7. This shows that to interpret the results of short-lived radon decay products measuring individual or as EEC, the differences in the equilibrium shift between radon decay products should be taken into account. Also at different aerosol particles concentrations, radioactive equilibrium factors and unattached fraction were determinated. Negative correlation between unattached fraction and the radioactive equilibrium factor, as well as positive correlation coefficient between the radioactive equilibrium factor and aerosol particle concentration in the standard radon box has been determined.

The influence of radon activity concentration on the value of ambient dose equivalent rate

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Reliable measurements of the ambient dose equivalent rate are crucial for monitoring environmental ionizing radiation. Typical applications are, for example, supervision of nuclear facilities or early warning stations for an emergency. Such dosimetric measurements must be able to detect even a slight increase in the background radiation caused by the presence of an artificial radiation source. The height of the natural background radiation consists of cosmic rays whose amplitude is small and the terrestrial radiation. Fluctuations of the ambient dose equivalent rate caused by the terrestrial radiation are often much higher than the required limit of detection of artificial radiation. The main reason for these fluctuations is related to changes in the concentration of radon and its daughters in the air. The aim of the work is to investigate the effect of radon activity concentration and size distribution of radioactive aerosol on the value of the ambient dose equivalent rate.

The measurements were carried out in laboratory conditions in the CLOR's radon chamber, for different radon activity concentration, relative humidity, temperature, concentration and type of ambient aerosols. The following parameters have been monitoring: particle size distribution of radioactive aerosols, radon activity concentration, potential alpha energy concentration (PAEC), radioactive equilibrium factor F, free fraction, ambient dose equivalent rate and gamma spectrum.

The goal of the work was to determine the influence of radon activity concentration, relative humidity, and particle size distribution of radioactive aerosols on the value of the ambient dose equivalent rate.

Reproducibility of radon-in-water measurements by emanometry technique

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Implementation of the Council Directive 2013/51/Euratom has led to a considerable increase of radon concentration measurements in drinking waters. The Directive indicates a detection limit (DL) of 10 Bq/L, i.e. 10% of the parametric value: this restricts detection systems to gamma-ray spectrometry (DL=10 Bq/L), liquid scintillation counting (DL=0.05–1 Bq/L), and emanometry, i.e. scintillation cells (DL=0.3–1 Bq/L), silicon-based detectors (DL=0.04–0.4 Bq/L) and pulsed ionization chambers (DL=0.3 Bq/L).

In order to evaluate the reproducibility of a commercial system based on emanometry technique, a measuring set-up consisting in three replicates of such system – each consisting of a degassing circuit coupled with a pulsed ionization chamber – has been realized at the National Center for Radiation Protection and Computational Physics of Italian National Institute of Health. A custom QA/QC protocol has been developed and it will be described. It mainly addresses: i) the assembling of each component of the three circuits, ii) the sample transfer from the transport container to the degassing vessel, iii) the behavior of laboratory expert during measurements, iv) warnings to prevent water flowing back to ion chambers. All the requirements included in the protocol aim to control influencing quantities and to verify stability of the detection chain.

The reproducibility of the system has been evaluated by measuring through the chains 40 different samples (120 measurements) of spring waters, with radon concentration ranging from few Bq/L ($<$ DL) to about 250 Bq/L. The coefficient of variation of the three measurements on each water sample ranged from 1% to 19%, with a median of 10%.

We have also taken part, with the same measuring chains, to the radon-in-water proficiency test organized by the European Commission's Joint Research Center, obtaining good results: the three systems returned values within the arithmetic mean $\pm 1\%$ (standard deviation with $k = 1$).

Intercomparisons of passive radon detectors

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Participation in interlaboratory comparisons is an important part of the quality control system. Comparative studies of passive methods of measuring radon concentration in the air were carried out in the Central Laboratory for Radiological Protection which is accredited by The Polish Centre of Accreditation in the field of calibration of radon devices and exposition of passive radon detectors.

Seven participants from Poland and two from Italy participated in the comparisons. The comparisons consisted of two exposures. The first exposure was conducted in a stable concentration of radon. During this exposure, the radon flow source was open throughout the duration of the exposure ensuring adequate air flow, taking into account the parameters of the source. The second group of detectors was exposed to the decreasing concentration of radon in accordance with the radioactive decay of ^{222}Rn. The average value of radon concentration (the reference value of radon concentration in the air during the second exposure) was 8 044 Bq/m^3. To achieve that value, the initial radon concentration in the chamber had to be set to approximately 12 kBq/m^3. Radon concentration was constantly monitored by the AlphaGUARD radon monitor during both exposures. The comparisons allowed to check the measurement consistency in both cases. After each exposure, detectors were sent back to the participants for reading and analysis. The z-score test has been selected for evaluation of the participant's results.

German approach to the implementation of the new radon dose conversion coefficient (ICRP 137)

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In Germany, the question about the new dose conversion factor is discussed very controversially and passionately.

Up to now, the dose coefficients from ICRP 65 (1993) are used to evaluate the individual dose for workers as well as for the assessment of the annual effective dose for members of the public. The reevaluation of the total detriment (ICRP 103, 2007) and subsequently of the lifetime lung cancer risk for miners in ICRP 115 (2010) has led to new dose coefficients that were more than twice as large as the coefficients from ICRP 65. Finally, the publication of OIR 3 (ICRP 137, 2017) with new nominal dose coefficients for practical radiation protection was published, based on epidemiological and new biokinetic models. In most cases this would lead to a doubling of the dose for workers.

The possible implications of the new dose conversion factors, practical, regulatory and political, were discussed between the different stakeholders. Especially, the national Commission for Radiation Protection (SSK) and the swiss-german Radiation Protection Association (Fachverband) expressed very relevant but also partly controversial arguments and opinions.

This presentation tries to summarize the positions of the involved parties and provides some personal insights drawn from the ongoing process.

Application of Geometric Mixture Model of Risk Assessment at Radon Exposure

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For a long time, multiplicative models of radiation risk (BEIR VI, Wismut, Czech–France cohort etc.) were considered as the main ones in the assessment of radiation risk during exposure to radon. However, considering these models for calculating the relative biological effectiveness or dose conversion factors by dose conversion convention technique for cohorts with low levels of smoking (females) led to results contradicting the elementary fundamentals of radiobiology. The main reason for this may be the deviation of the radiation risk model from multiplicative dependence. In recent years, a geometric mixture model of risk assessment at radon exposure has been proposed that takes into account both the additive and the multiplicative effects of radiation (Tomasek, 2011; 2013). This geometric mixture model was used for simulating of large-scale radon epidemiological study. Radon levels, smoking, attained age and lung cancer risks were set by Monte-Carlo technique. It was demonstrated that the standard calculation of the odds ratio leads to different dose-effect dependencies for samples with different levels of smoking (males, females, non-smokers, ex-smokers, etc.). Applying the geometric mixture model, the assessment of the relative biological effectiveness of alpha-radiation at radon exposure was carried out. The dose coefficients (mSv/WLM) for the conversion from radon exposure to the effective dose were calculated by dose conversion convention technique for cohorts with different smoking status. It is shown that using of the geometric mixture model results in better correspondence to basic concepts of radiobiology.

The influence of the F from RnDP inhalation for the estimation of the annual E in the selected workplaces

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As part of the project "Effect of the concentration and size distribution of aerosol particles on the ratio of an attached and unattached fraction of the radon decay products" (TITSSUJB702), which is solved under the Technology Agency of the Czech Republic, several interesting workplaces were visited. The main exposure pathways were identified at each workplace and the mean values of the radon activity concentration, radon decay products activity concentration, ambient dose rate equivalent and activity concentration of the long-lived radioactive dust emitting alpha particles were determined. The paper "The influence of the Equilibrium factor (F) from Radon Decay Products (RnDP) inhalation for the estimation of the annual Effective Dose (E) in the selected workplaces" describes the different possibilities how estimated the annual effective dose based on the measurement of the radon activity or radon decay products activity concentration.

Comparing radon health effects in the high exposure province Manitoba and the low exposure province Prince Edward Island

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Lung cancer (LC) is the leading cause of death of cancer in Canada in both males and females. Word Health Organization (WHO) consider indoor radon as the second leading causes of LC after tobacco smoking. LC, smoking, low and high indoor radon data in two Canadian provinces are used to investigate radon risk.

Methods: We compare LC rates and ever smoking (ES) percentages in Prince Edward Island (PE) and Manitoba (MN) to prove that ES percentages alone do not explain the high LC rates found in MN. We compare the radon levels in the two provinces and show that high radon levels explain well the LC rates in MN. We estimate the population attributable risk (PAR) and LC cases caused by radon at different radon levels to identify critical radon levels. We analyze and compare the sensitivity of PAR in PE and MN to both action and target radon levels. Finally, we estimate the burden of LC caused by radon in PE and compare the results and the population size to that in MN.

Results: LC cancer rates for males in MN are higher than that in PE. ES percentage (both genders) in PE is 18% higher than that in MN. ES percentages fail to explain the high LC rates for males in MN. Also, indoor Radon levels in MN are much higher than that in PE, which explains well the high LC rates for males in MN. PAR in PE is only 37% of that in MN. Radon above the action level 200 Bq/m^3 increases LC in PE by only 4 cases, but in MN by 195 cases. PAR in MN is more sensitive to change in action and target radon levels than that in PE. PAR is linear in target radon level with the slope in MN equals 8 times its slope in PE. Finally, PE population 2006–2009 was around 12% of that in MN, but disability-adjusted life years (DALYs) from LC caused by radon in PE are only 4% of that in MN. In sum, high radon levels in Canadian provinces causes many LC cases which leads to high burdens on Canadians health.

Conversion of radon exposure to effective dose

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The International Commission on Radiological Protection (ICRP) has recently published doses coefficients for the inhalation of radon, thoron and their airborne progeny as well as recommendations for their use for the protection of workers (ICRP Publication 137).

Although protection against radon is based on measurement and control of levels of exposure, dose estimates are required in certain situations for workers. Based on both dosimetry and epidemiological data, the Commission recommends the use of a single dose coefficient of 3 mSv per mJ h m^{-3} (11 mSv per WLM) for the calculation of occupational doses following exposure to radon (^{222}Rn) progeny in underground mines and in buildings, in most circumstances. However, for indoor workplaces where workers are engaged in substantial physical activities and for workers in tourist caves, a dose coefficient of 6 mSv per mJ h m^{-3} (21 mSv per WLM) is consider to be more appropriate. Site-specific dose coefficients can be calculated using the dosimetric data provide by ICRP, in special cases where exposure conditions are non-typical, and sufficient, reliable aerosol data are available.

In this presentation, the main issues in estimating and choosing dose conversion factors for radiation protection are discussed. Uncertainties in the ICRP dosimetric calculations and comparisons with other dosimetric models are presented. Recent epidemiological data including the published risk estimates from the German uranium miner cohort study are also discussed.

Lifetime risks in cohort studies of uranium miners

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The presentation includes models of excess relative risk derived from Czech, German and Ontario uranium miners developed for the UNSCEAR report on "Lung cancer from radon". The three studies of uranium miners are the largest cohorts of uranium miners (59 000, 28 500, and 10 000 miners in German, Ontario and Czech cohorts, respectively). The recent follow-up resulted in 3 942, 1 246, and 1 161 lung cancers, respectively. Generally, the risk models based on low exposure or low exposure rates are preferred because of more reliable exposure estimates in later periods. The standard projection models suggested in BEIR VI report include modifying effects of attained age, time since exposure, and exposure rate. In addition to model BEIR VI parameters estimated in the studies, the presentation will include an alternative model where the modifying effect of exposure rate is considered in dependence of actual annual exposure rates in contrast to mean exposure rate used in model BEIR VI. The second model uses all miners exposed to low exposure rates, whereas in the BEIR VI model the lowest category of exposure rate uses miners exposed only to low exposure rates. Higher numbers of cases in the latter model thus provide narrower confidence intervals in comparison to categories defined by mean exposure rates. The risk models will also be compared to 11 studies used in BEIR VI. The lifetime risks in the above studies will be based on excess relative risk and excess absolute risk models.

The UNSCEAR report on lung cancer from exposure to radon

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The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has previously considered the effects of exposure to radon and its progeny with regard to workers and the public in several reports. The Committee has assessed in detail the newly available literature since its UNSCEAR 2006 Report (Annex E: Sources-to-effects assessment for radon in homes and workplaces) and has confirmed that inhalation of radon and its progeny is an established carcinogen for the lungs.

The Committee reviewed in its latest report dosimetry assessments in homes, indoor workplaces and mines, and evalauted recent epidemiological studies (residential and occupational) of lung cancer risk from radon exposure, mostly in miners published since 2006.

The presentation will summarise the methodology applied for the report and the conclusions adopted by the Committee at its 66$^{\text{th}}$ Session in June 2019.

Genetic modifiers of radon-induced lung cancer risk in former uranium miners

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Objective: Radon is a risk factor for lung cancer and uranium miners are more exposed than the general population. A genomewide interaction analysis was carried out to identify genomic loci, genes or gene sets that modify the susceptibility to lung cancer given occupational exposure to the radioactive gas radon.

Materials and Methods: Samples from 28 studies provided by the International Lung Cancer Consortium were pooled with samples of former uranium miners collected by the German Federal Office of Radiation Protection. In total, 15 077 cases and 13 522 controls of European ancestries, comprising 463 uranium miners were compared. Single- and multi-marker models were fitted and an exploratory geneset analysis to detect significance in sets of genes was performed. Results: A genome-wide significant interaction of the marker rs12440014 within the gene CHRNB4 (OR = 0.26, 95% CI 0.11–0.60, $p = 0.0386$ corrected for multiple testing) was discovered. At least suggestive significant interaction of linkage disequilibrium blocks was observed at the chromosomal regions 18q21.23 ($p = 1.2 \times 10^{-6}$), 5q23.2 ($p = 2.5 \times 10^{-6}$), 1q21.3 ($p = 3.2 \times 10^{-6}$), 10p13 ($p = 1.3 \times 10^{-5}$) and 12p12.1 ($p = 7.1 \times 10^{-5}$). Genes belonging to the Gene Ontology term "DNA dealkylation involved in DNA repair" (GO:0006307; $p = 0.0139$) or the gene family HGNC:476 "microRNAs" ($p = 0.0159$) were enriched with LD-block wise significance.

Conclusion: The well-established association of the genomic region 15q25 to lung cancer might be influenced by exposure to radon among uranium miners. Furthermore, lung cancer susceptibility is related to the functional capability of DNA damage signalling via ubiquitination processes and repair of radiation-induced double-strand breaks by the single-strand annealing mechanism.

Occupational exposure assessment against radon risk in some thermal stations in eastern Algeria

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The evaluation of the occupational exposure to radon is crucial for human risk assessment, since radon (^{222}Rn) can be consider a hazardous carcinogen depending on the effective doses that a person is exposed to. Therefore, the Centre de Recherche Nucléaire d'Alger has carried out a research work that aimed mainly to assess the radon risk for workers in Algerian thermal resorts. These investigations have been carried out in different thermal stations located in the eastern part of Algeria [1, 2].

In the present work, the results of the exposure assessment of workers at four thermal stations namely, Hammam Ouled-Yelles, Hammam El-Sokhna, Hammam Ouled-Ali and Hammam Guergour, are presented. Both atmospheric and water radon concentrations were investigated. Complementary techniques have been also used in order to determine the radon exhalation from soil, indoor and outdoor gamma doses, as well as uranium concentrations in soil and in water.

Results show that the highest indoor radon concentration obtained value is about 1.3 kBq/m^3; this concentration has been recorded around the hot swimming pool of Hammam Ouled-Ali. However, radon concentrations in the investigated sites have been found ranging from 11 Bq/L to 160 Bq/L. The corresponding doses due to radon received by workers in different investigated thermal stations are found ranging from 5 to 19 mSv/year. These doses are high and thus suggest that special actions should be undertaken to reduce the radon exposure around thermal pools in such stations.

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Radon measurements in groundwater geothermal water of the western Anatolia

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Radon gas is the most important source of irradiation with natural radiation. This is due to the alpha particles adhering to small particles in the air and radionuclides, the short-term decay products of ^{222}Ra, which irradiate lung tissues and increase the risk of lung cancer. It is well known that radon is soluble in water and the solubility of radon increases rapidly at a reduced temperature. Therefore, investigation of radon activity levels in drinking water, ground water and geothermal waters is very essential for determination of radiation exposure depending on water usage. In this study, the radon concentrations in groundwater and geothermal water samples, which collected from geothermal areas and natural springs of the western Anatolia, were measured by using AlphaGUARD PQ2000Pro has several components for different applications. AquaKIT was used for the determination of solved radon in water for 12 locations in western Anatolia. The results obtained from the present study varies between 1.392 and 27.82 Bq/L. The annual effective doses received by local residents and visitors was calculated.

Validation and quality assessment of a solid state nuclear track detector method of indoor radon monitoring for long exposures

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Radon inhalation is the second leading cause of lung cancer as control of public exposure to the gas is recommended by the World Health Organization. To develop consistent monitoring programs, quality control must be an essential part of radon concentration assessment indoors. The study focuses on the validation of a solid state nuclear track detector (SSNTD) technique, executed by assessing quality parameters of trueness, precision, linearity, limit of detection, robustness and measurement uncertainty. Radon concentration data applied those statistical studies were sourced by a proficiency testing scheme of passive detectors, which produced 60 radon exposure results from 5 different concentration points in the range of 150–2500 kBq/m^{3}h. Criteria used to evaluate the quality studies were based on the Quality Management System established at Poços de Caldas Laboratory-CNEN. Although the assessment of trueness identified a negative bias towards higher concentration ranges, results of precision suggested highly reliability to the use of CR-39 detectors for 1-year exposure periods. A strong positive correlation ($R = 0.999$) between reference values and data obtained from the proficiency test was pointed by the linearity evaluation while assays of robustness evidenced critical conditions to the stage of detector post treatment within the SSNTD technique. A comparative study of detection limit determination (LOD) allowed choice of the best fit for long exposure periods using passive detectors. While the 3 methods compared produced similar results, the selection took into account the number of variables involved in the estimation and a conservative viewpoint in terms of the observed outcomes. The measurement uncertainty study, which compared manual and automatic approaches, points to the challenges faced by the Laboratory in terms of finding coherence between approaches that should produce statistically similar results. Method validation and quality control practices are essential tools in the quest for dependable results while providing useful indicatives of continuous improvement opportunities.

Evaluation of radon indoor concentration levels in three Brazilian municipalities

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The objectives of this paper are to describe indoor radon concentration measured inside dwellings in the Brazilian southeastern municipalities of Andradas, Caldas and Poços de Caldas and to evaluate the association between dwellings' features as well as residents' behavior and observed radon concentration values that are greater than or equal to 200 Bq/m^3. This is a longitudinal study that measures public exposure to radon indoor in three municipalities of the Poços de Caldas Plateau in two distinct seasons. In both occasions analyzes were performed considering measurements taken in bedroom and living room both separately and combined. The level of 200 Bq/m^3 was adopted as a reference level for health risks. According to results, 123 out of 577 households presented radon concentrations $\geq$200 Bq/m^3, occurring mainly in rural areas. The households with the highest levels $\geq$ 200 Bq/m^3 were those located in Caldas and Poços de Caldas municipalities (OR = 2.94, 95% CI 1.55–5.57 and OR = 2.45, CI 95% 1.36–4.42, respectively); those located in the rural area (OR = 2.26, 95% CI 1.35–3.79); those constructed before 1976 (OR = 2.35, IC 95% 1.35–4.06); those with bedrock of bedroom suspended (2.57, 95% CI 1.39–4.75), and those whose windows are not kept opened at night (OR = 2.18, 95% CI 1.30–3.66). The results indicated high levels of indoor radon ($\geq$ 200 Bq/m^3), with more than half of the households with at least one measure higher than those recommended by the World Health Organization (100 Bq/m^3). It was also observed that some dwellings characteristics (rural areas, older construction, solid foundation), as well as residents habits (sleeping with closed windows) may contribute to increase radon indoor levels.

Radon in mines of Kryvyi Rih iron ore basin

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Despite the long history of the problem of radon in mines, the first studies of radiation factors in old mines of the Kryvyi Rih Iron Ore Basin began relatively recently, about 20 years ago. The results of these studies have shown that radon problem occurred in most of the basin mines. The excess of the normative value for the equilibrium-equivalent decay-product concentration (EEDC) of ^{222}Ra in the mine atmosphere of the main workplaces was observed in 6 of the 8 studied mines. According to the sum of the main measured radiation-hazardous factors, a preliminary assessment of the dose loads on the underground personnel was carried out and the classification of the Basin's mines on Radon hazard was fulfilled. According to the degree of radon danger, all the mines were divided into three categories: radon-hazardous, moderately radon-hazardous and radon-safe. The mines in which the annual effective dose for workers in basic occupations does not exceed 1 mSv on the sum of radiation-hazardous factors are classified as radon-safe. Mines with an annual effective dose to miners of more than 1 mSv but less than 5 mSv are moderately radon-hazardous. Radon-hazardous mines are those with an annual effective dose to miners of more than 5 mSv.

The geology of the Basin is briefly highlighted and the sources of Radon in the mine workings are discussed. The results of recent radiation surveys of these mines are given. Measures are being considered to improve radiation monitoring methods in the mines of the Basin.

History of radiation protection in uranium mining in CR (CSSR)

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The paper attempts to map the development of radiation protection in uranium mining since 1961, including the currently valid legislation. In 1966, the limit value for the latent energy concentration of radon decay products was set for the first time at 4.104 MeV/L. In practice, this meant the necessity of radon daughter products measurement. In 1972, the Hygienic Directive set a value of 4.104 MeV/L resp. 6.104 MeV/L as the highest permissible exposure for calendar quarter, resp. for the year and also issued a regulation of workers' exposure in case it was exceeded. It introduced the limit of annual latent energy intake of 8.1010 MeV. In 1976, the value of 9.1010 MeV was set as the highest annual dose for a worker and the value of 8.1010 MeV as the average annual dose for a team of workers in the entire mine. In 1992, the DIAMO s. e. director's Directive ordered tightening of the annual limits for inhalation intake and the average activity of a mixture of long-lived uranium-radium decay chain alpha emitters (1 700 Bq and 0.708 Bq/m^3).

Since 1995, the State Office for Nuclear Safety has been supervising the radiation protection and nuclear safety in the uranium industry. In 1997 the first Atomic Act and implementing Decrees came into force. In 2016 a new Atomic Legislation was implemented. For irradiation by mixture of long-lived radionuclides emitting alpha particles from uranium-radium decay chain, a derived annual limit of 3 200 Bq (respiratory rate 1.2 m^3 h^{-1} was set. In case of irradiation caused by radon daughters, the 'derived' limit of 3 MBq for the annual intake of equivalent radon activity remains equal to the latent energy intake of 17 mJ radon products, or the exposure to radon products 2.5 MBq h^{-1} m^{-3}, or annual average equivalent to a radon activity concentration 1 260 Bq m^{-3}.

A number of miners have, over time, developed illnesses which are being evaluated with respect to irradiation by radon daughter products.

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^{222}Rn level in water and its effective dose around Doi Saket region, Chiang Mai, Thailand

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In this study, the mesurement of radon concentration to estimate the intake effective dose in tap water and well water was carried out in the villages located in Doi Saket district, Chiang Mai, the famous tourist landmark of Thailand, by using RAD7 an electronic Radon detector. The water samples, including 22 tap water from public water supply and 8 well water, were collected from 30 sites in the villages. The measured radon concentrations in the well water and tab water samples ranged from 11.35 ± 4.15 to 84.20 ± 23.23 Bq/L and 0.11 ± 0.02 to 60.91 ± 14.17 Bq/L, respectively. All well sample has the concentration level higher than the maximum contamination level (MCL) of 11 Bq/L in drinking water set by the Environmental Protection Agency (EPA). However, the concentration of radon in those water samples collected from both sources, is less than the reference level of 100 Bq/L set by World Health Organization (WHO) and European Union Commission (EU) for drinking water. The estimated annual ingestion and inhalation dose due to drinking and using well water were found between 0.80–614.70 μSv/y and 0.28–212.20 μSv/y respectively. It was found that 75% of all samples of well water have higher values than annual dose limit for ingestion recommended by WHO of 0.1 mSv/y. While 2 of 22 samples of tap water supply, originated from mountain water, have higher values than annual dose limit.

Natural radioactivity in one Brazilian underground mine: case studying

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Rock, soil and water contain ^{238}U and ^{232}Th and their decay products. The distribution of these radionuclides in the rocks of an underground environment differs in terms of activity concentration and it depends on the mineral type, origin and geochemistry condition of the underground environment. All ore processing releases long and short half-life radionuclides, mainly radon and its progeny. It is important to monitor this gas and its decay products in underground mines in order to assess the radiological hazards of the exposed workers. On this concern, the present work outlines the studying of the natural radioactivity in the specific Brazilian underground mine which showed high radon concentration in some measurements campaign. The radon concentration was measured by using E-PERM Electrets Ion Chamber (Radelec), AlphaGUARD (Saphymo GmbH) and CR-39 (Landauer) track etch detectors. The radon progeny was determined by using DOSEman (SARAD) detector. The equilibrium state between radon and its progeny was determined. A radiometric survey with RS-230 BGO spectrometer was carried out on the region. Based in these results, total effective dose was estimated. A high counting rate were observed in there region and the radon and its progeny concentration in the air ranged inside mine (113 to 8 171 Bq/m^3). Therefore, results show the importance to assess continually and permanently the radon and its progeny behavior and the need to adopt safety measurements against natural radiation in underground mines environment.

Survey of indoor radon levels in some universities in South Western Nigeria

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Indoor radon investigation was carried out in offices of three university campuses located in South Western part of Nigeria; Federal University of Technology Akure (FUTA), Ekiti State University (EKSU) and Federal University Oye-Ekiti (FUOYE) using CR39 detectors. The mean activity concentration of indoor radon for the investigated offices of all three university campuses was estimated to be 222 ± 44 Bq/m^3, which was below the reference level of 300 Bq/m^3 recommended by the International Commission on Radiological Protection (ICRP 115). For the three institutions, the probability of lung cancer induction at age 70 years with respect to age of exposure (40, 50, and 60 years) ranged between 1.06×10^{-7} and 6.24×10^{-5}. The expected mortality rate due to exposure to a radon activity concentration ranging from 7 to 1 358 Bq/m^3 was estimated to range from 0 to 44 deaths among a population of 10 000 persons.

Estimation of cancer risk due to indoor radon from some selected homes in South Western Nigeria

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Indoor radon measurements in 158 homes of selected towns/cities in South Western Nigeria with the aim of estimating the Excess Life-time Cancer Risks (ELCR) have been carried out using CR-39 Solid State Nuclear Track Detectors (SSNTDs). The measurements were done for six months. Radon concentrations were found to be in the range 14–291 Bq/m^3 with arithmetic mean of 64.78 ± 37.21 Bq/m^3 and geometric mean of 56.00 ± 2.00 Bq/m^3. Annual effective doses (AEDs) were estimated from the measured radon concentrations with a mean of 1.86 ± 0.74 mSv y^{-1} which was observed to be higher than the world average level of 11.15 mSv y^{-1} but lower than the lower limit of 3.0–10.0 mSv y^{-1} recommended by the International Commission on Radiological Protection (ICRP). The mean AED translates to ELCR of about 0.7%. The influence of building characteristics such as main building materials, flooring materials, age of the buildings, ventilation and water supply on measured indoor radon were investigated. The results showed that the health hazard due to radon is negligible.

OPTI-SDS project: contributions to the NRCS in Ireland and international collaborations investigating radon mitigation

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The OPTI-SDS project has investigated the optimum specification for soil depressurisation (SD) systems (active and passive) that take account for Irish Building Practices. The impact of the aggregate layer on the effectiveness of the SD systems was investigated under laboratory conditions. Characterisation of standard Irish granular fill materials T1 Struc and T2 Perm was performed, including particle size distribution, compaction degree and air permeability and porosity of the materials. Small-scale and large-scale experimental tests were conducted and a novel test apparatus developed for this investigation. Performance of a variety of rotating and static cowls used for passive soil depressurisation system was also investigated. Computational Fluid Dynamics (CFD) simulations for the design of SD systems were performed. Numerical models were developed and validated using experimental tests, considering the input parameters detail and boundary conditions. Effectiveness of radon mitigation solutions through collaboration with European partners was also quantified. Spanish granular fill materials were benchmarked against Irish standards and a case study was conducted in a pilot house with high radon levels in Spain to examine the ability and efficiency of radon mitigation by SD. Radon concentration and pressure field extension under the slab were monitored in the pilot house to examine radon reductions as a function of the depressurisation.

Applicability of ventilation systems for reducing the indoor radon concentration

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Various systems of mechanical ventilation are often used to ensure high quality of indoor air in residential buildings. These systems are also considered as a means of maintaining indoor radon concentration at an acceptable level. Their ability to reduce the radon concentration depends on the radon supply rate and ventilation intensity with which the ventilation system operates. Due to the general effort to minimize the energy consumption of buildings, it is not possible to increase the ventilation intensity to indefinitely high values. For this reason, the effectiveness of ventilation systems in reducing the radon concentration is limited by a certain maximum level of ventilation intensity, above which the ventilation system becomes energetically unacceptable.

In this context, the objective of our study was to find the area of applicability of ventilation systems, i.e. to find a range of acceptable values of ventilation intensity depending on the radon supply rate and the required/acceptable value of indoor radon concentration. For that purpose, a simple ventilation model RaVen has been developed. RaVen is a single-zone model based on repeated solution of the balance equation between the incoming and outcoming amounts of air. After validating the model by comparing its outputs with the time courses of radon concentration measured in real buildings, the model was used for simulating various ventilation modes. We investigated systems operating in both continuous and cyclic modes, with constant ventilation intensity and varying ventilation intensity. For each ventilation mode, we monitored the rate of decrease in radon concentration below the required value, the rate of increase in radon concentration after switching off the ventilation and the energy consumption. The developed model was found as a suitable tool for designing ventilation systems to reduce radon concentration.

Radon mitigation actions in large public buildings: some review and a case study

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In the last 30 years, a lot of experience in radon mitigation has been gained in many European and other countries, but even when the mitigation is not concerning single houses, it is often addressed to small buildings or to the parts of the buildings directly connected to the ground.

The experience in large public buildings comes mainly in applying mitigation measures to buildings used for kindergartens and schools that are often large but not very complex: they often cover a large surface area but they generally have few floors and the structure of the building is relatively simple.

Performing an adequate monitoring of radon concentration within large buildings, especially for the evaluation of mitigation effectiveness, can also be quite more difficult than for a dwelling or a small building.

In Italy, several large public buildings were built more than one century ago, usually with thick walls, age-specific building details, missing or inaccurate blueprints, significant differences between blueprints and the actual situation, unknown structures (even if blueprints exist), with few information on the characteristics of building foundations and of the soil below the building.

This study will present some review of remedial actions and radon concentration measurement approach in large buildings. Moreover, the mitigation system and the radon concentration monitoring system installed in one of the largest Italian public buildings (an historical building built in the 19th century) will be illustrated, together with some preliminary results.

Radon measurements in big buildings

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The general purpose of radon testing is to identify locations that have elevated radon concentrations and to determine if mitigation or remediation is needed. This requires a basic understanding of radon dynamics as well as development of appropriate testing procedures is necessary. The main propose of this study is definition of classification criteria, or parameters influencing on radon dynamics in big buildings which could include number of floors, ground floor features, type of ventilation etc. Indoor radon measurements were conducted in about 50% of all rooms in 3 big buildings with 9 or more floors using track detectors. Frequency distributions of indoor radon concentrations by floors were estimated. Obtained results can generally be approximated by lognormal distributions. These log-normal distributions allow to assess the number of measurements in the big buildings which are necessary to obtain a mean value with pre-set uncertainty. Ten measurements are sufficient for radon concentration estimation with an uncertainty 50%, 20 measurements are enough for 30% uncertainty. Concerning measurements in multi-storey buildings, radon concentrations distributions are quite homogeneous. This homogeneous is associated with minor differences in the sources and mechanisms of radon entry at ground floors. In these cases, the building materials form the main contribution to radon concentration.

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The influence of pinholes in waterproofing materials on the value of the radon diffusion coefficient

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It is easy to make the unintended holes or imperfections in waterproofing materials during the construction of a building. The unprotected waterproofing material can be damaged while walking over it by seemingly miniscule stone attached to the sole of a shoe or by sharp fragments of building materials. Through these damages, which are often made on building site by an accident, radon can get inside the building.

The paper focuses on the experimental study of the influence of imperfections on the value of the radon diffusion coefficient of different waterproofing materials. Microscopic holes were made by thin tip or micro drill bit imitating a real damage during construction. To determine the change in the radon diffusion coefficient, each waterproofing material was measured 5 times. The first measurement was on undamaged samples, while the following measurements on samples with one, two, four and eight pinholes. Measurement of the radon diffusion coefficient was performed under nonstationary conditions because of the usage of homemade radon sources with slow rate of radon emanation. Radon diffusion coefficients identified in the study were compared depending on the thickness of the material and number and size of pinholes. The exact shape and size of the imperfections were documented by an electron microscope.

The occurrence of pinholes in waterproofing materials negatively affects the long-term functionality and reliability of protection against radon. The study showed how pinholes act as open gates for radon and the fact that they significantly increase the radon diffusion coefficient of the material.

Passive soil depressurisation systems: current and future perspectives

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There is strong evidence both internationally and in Ireland that the correct installation of passive prevention systems in new buildings is the most cost-effective way of protecting the population against radon. Previous work considering membranes, granular fill material in the aggregate layer beneath the slab and sump system has been conducted in Ireland to improve the protection of buildings from radon. The implications of research on passive sumps potential to reduce radon concentrations are significant, as if it can be shown that the installation of passive sumps in Irish building is effective, this could constitute a low-cost, passive, sustainable method for minimising radon levels in buildings. An overview of the state of the art developments on the topic and the on-going experimental tests investigating the performance of different common cowls used for passive soil depressurisation systems are presented. In addition to the impact of different vertical heights and horizontal lengths of pipe with a number of bends investigated.

A field study of passive radon stacks in Canadian homes

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In 2014, British Columbia (BC) became the first province in Canada to mandate the installation of a full height passive radon stack in their radon-prone (Area 1) regions.

From December 2018 to April 2019, the National Research Council (NRC) Canada conducted a comprehensive investigation on this topic in 15 newly built homes in BC. The study compared the indoor radon measurements in each house with the stacks opened and closed for a period of at least 30 successive days. During the testing period, the radon concentration in the basement, the pressure underneath the concrete slab, and the air speed within the stack were measured.

The following major observations were made based on the test results in the 15 study homes:

- During the first testing period, between December 2018 and February 2019, the passive radon stacks reduced the indoor radon concentration by 60–90% in 10 study homes and by 30–40% in the other 5 homes;
- During the second testing period, between March and April 2019, the passive radon stacks reduced the indoor radon concentration by 40–90% in 9 study homes; whereas the radon reduction rate in 4 homes decreased to 5–30% range. The decrease in the radon reduction rate observed from the 2nd stack open/close cycle can possibly be attributed to stack blockage from snow and/or ice during the winter months;
- Furthermore, negative radon reduction rate could be observed in 2 study homes during the second testing period, between March and April 2019; in other words, the indoor radon concentrations in these two homes were higher when the stacks were open than the indoor radon readings when stacks were closed. The research team has contacted the homeowners to verify if major changes were made to the basement building envelope and/or to ventilation strategies;
- The testing results indicated the effectiveness of full height passive radon stacks in reducing indoor radon concentration is affected by the length of the stacks in unconditioned space and the distance between the stack and the exterior walls.

Radon series in energy efficient buildings

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Nowadays, humanity is confronted with the need for global energy savings and reduced energy consumption. Housing and communal service spheres consume about 40% of energy resources. A number of architectural and technical solutions aimed at the heat saving have been developed in the construction industry including follows: special coatings of walls, PVC windows etc. Architectural and construction solutions proposed up to date utilize the potential of both thermal radiation and air exchange rate. The study of physical basis of indoor radon concentration changes in energy efficient buildings is of current interest. Analysis of long-term radon series using a radon monitor has been used as a method for studying radon entry and accumulation. Radon monitor was installed for a period of 2–6 months in high-class energy efficiency buildings: multi-story houses, single family detached houses, kindergartens. Both energy retrofitted and new energy efficient buildings were studied. More than ten radon series were obtained. Analysis of the series allows to make conclusions on influence of different anthropogenic factors on indoor radon concentration in energy efficient buildings. The most important factors are uncontrolled air exchange rate under passive mode of exploitation and ventilation preferences of dwellers. Indoor radon concentration is significantly modified if mechanical supply exhaust ventilation is installed.

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Pilot house study on active and passive soil depressurisation for radon mitigation: Rn concentration and PFE monitoring

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A one-year monitoring study was conducted in a pilot house with high radon levels to investigate the ability and efficiency of radon mitigation by soil depressurisation (SD) both active and passive. The study included monitoring of radon concentration, pressure field extension (PFE) under the slab and some atmospheric parameters for different testing phases. Periods in which the house remained closed to foster radon accumulation were alternated with phases of active and passive soil depressurisation under different conditions. The behaviour of the radon concentration in the pilot house was analysed along with the influence of atmospheric variables, significant correlations were found for the radon concentration with atmospheric pressure, outdoor temperature and wind. From the PFE analysis it was proven that the pressure drop with distance from the suction point of the SD system is proportional to the depressurisation generated. It was also found that the permeability characterisation of the pilot house agrees with the literature about granular fill materials characterisation for radon SD systems across Europe. Radon reductions in excess of 85% were achieved for the different testing phases in all cases. Finally, from the results it was stated that a fan power of 20 W is sufficient to ensure radon reductions over 85% for dwellings with similar aggregate layer and soil permeability.

Variation of radon activity concentration in traditional russian wooden houses

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The purpose of this work is the study of temporal radon variations in traditional Russian wooden houses (izba). These houses are widespread in Russia and make up about 50% of the total number of individual buildings. Russian izba is characterized by the unimpeded transport of radon from the soil into the dwelling through the slits in the floor, which causes increased concentrations of radon in houses, despite the absence of radium in building materials. The series of radon continuous measurements lasting from two weeks to one month (summer 2017, summer 2018, winter 2019) were carried out in two houses located in different villages in the Moscow area at a distance of ca. 80 km from each other. In both cases, the base soils are low-permeable glacial loams with a radium content of 35–45 $\mathrm{Bq\,kg^{-1}}$, the radon activity concentration in soil gas at a depth of 0.8 m is 8–16 $\mathrm{kBq/m^3}$, the radon flux density (RFD) from the soil surface is about 75 $\mathrm{mBq\,m^{-2}\,s^{-1}}$. In houses the same pattern of radon variations is established. During the summer, the radon activity concentration in homes (C_{Rn}) ranges from 5 to 270 $\mathrm{Bq/m^3}$ (avg. 80 $\mathrm{Bq/m^3}$) and is characterized by a clear diurnal rhythm with maximums at night and minimums at day. The C_{Rn} has a clearly positive correlation with the temperature difference inside and outside the house (ΔT) and a negative correlation with the wind speed. In winter C_{Rn} ranged from 50 to 470 $\mathrm{Bq/m^3}$(avg. 230 $\mathrm{Bq/m^3}$) and no daily fluctuations were observed. C_{Rn} was inversely proportional to the ΔT, and no correlation with the wind speed. Regardless of the season, the ventilation of the premises by residents, as well as fluctuations of RFD from the soil surface practically does not affect the C_{Rn}. The report discusses the causes of the observed phenomena.

The NRPI integral system for the measurement of an average air exchange rate in buildings

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The air exchange rate between indoor and outdoor air is the key physical process which influences among other things also behavior of all types of aerosol and gaseous contaminants, including radon gas in buildings and mediates their transport from the outside air to the interiors of buildings. Measurement of the air exchange rate in buildings plays the important role for dose assessment from inhalation of radon gas and also provides a new diagnostic tool for evaluation of magnitude and pathway of radon entry rate. Hence, a several years ago, a new technique and method for determination of an average air exchange rate in buildings (apartments, multiple storey family houses, kindergartens, etc.) have been developed at the National Radiation Protection Institute of Prague (NRPI). Recently, the method has been certified by the highest relevant Czech state authority – the State Office for Nuclear Safety and used technique accredited. Currently, both the method and the technique are used in practice in the frame of the Czech National action plane in accordance with an applicable legislation.

After introduction of the self technique, a some examples of its use in field and the most interesting results will be presented. Generally, used multi tracer gas approach allows wide-spread survey in buildings and estimation of the air exchange rate ranging from 0.05 h^{-1} to approx. 3 h^{-1} within exposition duration lasting from a several days up to a several months and evaluation of inter-zonal airflows between rooms and floors. A typical total uncertainty of estimation air exchange rate is about 20% for coverage factor $K = 1$.

The NRPI multi-tracer gas PFT method as a new radon diagnostic tool

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A several years ago a passive multi tracer gas method has been developed at the National Radiation Protection Institute (NRPI). The method is based on use of a five perfluorocarbon tracer gases and GS chromatography. It allows to calculate both average air exchange rate in homes and inter-zonal airflows between rooms or floors of multi-storey family houses in a sufficient dynamic range within a several months and with acceptable total uncertainty up to 30%. Due to it's a unique property to estimate also inter-zonal airflows the method can be also used in the radon diagnostics for tracing of a radon pathway into a house and for calculation average sum of radon entry into investigated volumes of the house. The NRPI multi-tracer gas method was successfully compared with the PFT tracer gas method of the National Brookhaven Lab. NY U.S.A. in field of 10 different family houses and recently its chromatographic part has been accredited.

Brief description of the NRPI method will be followed by the discussion of the application of the NRPI method in field conditions from the point of view of assessment of the average sum of radon entry rate.

Study of radon exhalation rate from rocks. Analysis of results and uncertainties using short and long duration methods.

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Long-time exposure to high concentrations of indoor radon (^{222}Rn) constitutes a public health problem. The indoor radon concentrations depend on a large variety of factors, being one of them the ^{226}Ra concentration present in the building materials. For this reason, it is convenient to study the radon exhalation rate from building material components in order to take decisions on whether or not using some specific natural raw materials as aggregates of concrete. In this work we present a study of the radon exhalation rate from rocks susceptible of being used as aggregates in the Canary Islands, Spain, with different contents on radium and physical characteristics. For the determination of the exhalation, a series of radon accumulation experiments in a closed chamber were performed, using two procedures one short (< 48 h, linear regression) and another one long (> 48 h, exponential fitting) for comparing their results, uncertainties and detection limits. For such experiments, the rocks were triturated until achieving a particle size of less than 2 mm. Sampling time during the accumulation experiments was 10 minutes using the AlphaGUARD continuous radon monitor in diffusion mode. The results obtained show that, in general, the short and long methods are equivalent when the radon saturation activity concentration in the chamber is enough high above the lab background. For values near to the radon background due to low exhalation rate of the sample, the uncertainties of the short method do not recommend to use it. To optimize the long method, it was studied the minimum time necessary to obtain accurate results since the shorter duration of the method present obvious advantages when is necessary to measure big amount of samples.

Estimation of radon potential by means of measuring uranium concentrations in granite geology

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Globally, exposure to high levels of radon gas is a known health risk. Granite commonly contains high concentrations of uranium and subsequently high exhalation of radon gas. In the Saldanha Bay area of South Africa, granites dominate the underlying geology as well as the surface characteristics of the area. This imply that elevated levels of radon gas may exist in houses in the area. A recently published article predicted potentially high radon levels in houses of the area by modelling a granite outcrop outside the town of Saldanha, and interpolating the results to populated areas inside town. Preliminary measurements however showed indoor radon concentrations well below the world averages. In this article, researchers develop a theory, based on the influence of meteorological factors and building styles on the lifestyle of the inhabitants of the area, to explain the mitigating effect on the predicted elevated radon gas levels and associated health hazard posed by it.

Highly sensitive passive radon detector with compensated temperature dependence and thoron interference

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New kinds of passive radon detectors employ alpha-track detector coupled with a radiator of high radon absorption/adsorption ability [1]. The response of the most sensitive detectors of this kind (with radiators of Makrofol N or activated carbon) decreases significantly with the increase of temperature and activated carbon is also affected by humidity. We propose a new concept in which the radon detector is placed in a module [2] that compensates the temperature dependence of the detector. The module is a hermetically closed volume with one or more sides covered by a polymer foil through which radon can diffuse. As the permeability of the foil increases with the temperature, at constant ambient radon concentration the concentration inside the module will be higher at higher temperature. By proper choice of the volume, foil material and its thickness the temperature dependence of the detector can be compensated. We demonstrate results of pilot experiments with modules with foils of low density polyethylene of thickness 50 and 75 μm. The detectors are of Kodak-Pathe LR-115/II covered by absorber of Makrofol N or by adsorber (sheet of activated carbon fibers Kynol 507-10). When exposed outside the module the response of these detectors drops between 5 °C and 35 °C almost by factor of 3. When placed in the module the variation of the detectors response is reduced to less than 10% within 5–35 °C. Such module also serves as a barrier against humidity and thoron. The design of a new generation of highly sensitive radon detectors with compensated temperature dependence and unaffected by humidity and thoron presence is discussed.

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Mapping to assessment the radon risk areas in the Cap Bon Regions, Tunisia

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Radon concentrations in soil along with the terrestrial (in the hollowness of the pit) dose rate have been measured in the different geological formation of northeastern Tunisia (Cap Bon REGIONS). SSNTD AlphaGUARD PQ2000 active ^{222}Rn detector was used to determine Radon concentrations and the FH-40 radiameter was used to determine the dose rate. Gamma spectroscopy was performed in laboratory to determine the concentrations of ^{226}Ra source of radon gas. The activity concentrations were determined by direct counting using a hyper pure germanium (HPGe) detector inter phased with a multi channel analyzer. Radon gas concentrations were found to vary from 0.5 kBq/m^3 to 15.3 kBq/m^3 with a mean value of 4.2 kBq/m^3 in soil gas. The soil radon concentrations were found positively correlated with ^{226}Ra values and the terrestrial dose rate. The GPS coordinates for each measurement point were recorded in order to make a cross mapping of radon gas, ^{226}Ra and dose rate using the Geographic Information System (arcGIS).

Determination of geogenic radon potential (georp) in Poços de Caldas – Brazil

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Poços de Caldas plateau is located in the southern part of Minas Gerais State in Brazil, that municipality has over 160 000 inhabitants and is best known for being a touristic city with an altitude around 1 300 m and for its hot springs. The urban area is settled inside the so-called Poços de Caldas Alkaline Massif, a complex area with the shape of a volcanic crater that is of about 30 km in diameter. The massif was basically formed by igneous intrusion in the metamorphic basement usually called Pinhal Block. The region has deposits of bauxite due to the action of weathering on igneous rocks, as well as anomalies of uranium, thorium, zirconium, vanadium and rare earths due to hydrothermal alteration.

The region is known as "high natural radiation area" and because of that, there is a concern among the population about a possible association of cancer cases and radiation exposition.

This paper uses the Geogenic Radon Potential (GEORP) approach aiming to identify radon prone areas in the urban zone of Poços de Caldas – Brazil. GEORP encompasses simultaneous measurements of the soil gas permeability and radon soil gas concentration. This investigation was accomplished using RADON-JOK permeameter, a device specially developed for in situ soil gas permeability, and ALPHA-GUARD, a professional radon monitor. A large variability was observed in both radon soil concentration and soil gas permeability. Some areas have presented low gas permeability due to clayey soil characteristics thus medium GEORP. The majority of the points in this paper have been identified with high radon soil gas concentration showing values that reached 1 000 kBq/m^3 and presenting high radon index.

Estimation of indoor radon concentrations and exhalation rates from soil in the Tamanghasset district environment, Algeria

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Radon (^{222}Rn), the daughter products of radium in the naturally occurring uranium (^{238}U) serie, may cause a significant health hazard in indoor environments like dwelling and workplace. For public health risk assessment, indoor radon levels in dwellings and radon exhalation rates from soil samples collected from different locations in Tamanghasset district, mainly formed by granites-gneisses and basalts formations, are measured using active radon monitor and passive integrated dosimeter based on LR-115 solid-state nuclear track detector.

The results show that the indoor radon levels varied from 11 to 112 Bq/m^3. The indoor radon levels of 95% locations lie well below 300 Bq/m^3 the limit recommended by International Commission on Radiological Protection [2]. Uranium concentration in soil samples has been found to vary from 11 to 277 Bq/kg. The radon surface exhalation rate varied from 0.3 to 97.0 mBq m^{-2} s^{-1}. A positive correlation coefficient ($\varrho = 0.43$) has been observed between uranium concentration and radon exhalation rate of soil samples.

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Variations in soil radon levels and radon activity concentration in basement during winter and spring periods

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Radon forms the majority of the effective dose received from natural sources. Radon and its progeny make up 56% (2.19 mSv per year) of natural radiation exposure dose in Russian Federation.

The goal of this study was to improve the understanding the mechanism of radon transport from clayey soil to atmosphere. Measurements of radon flux density (RFD) from soil surface and radon activity concentration (C_{Rn}) in soil gas on the depth of 0.5 m have been performed over the course of winter (Dec–Feb) and, partially, spring (Apr–May) on the experimental site, located on territory of Moscow University Radiochemistry division. Based on the obtained data, it was determined that radon transfer is adequately described by a diffusion model and effective diffusion coefficient has been calculated: $D_e = 2.8 \cdot 10^{-6}$ m^2/s.

RFD and C_{Rn} have been compared to meteorological data (ambient air temperature, soil surface temperature, soil temperature on depth of 0.5 m, pressure, air humidity and wind speed) and several correlations have been observed. It has been found that RFD correlates positively ($R = 0.57$) and $\mathrm{C_{Rn}}$ correlates negatively ($R = -0.41$) with air temperature during the winter period. During spring no correlation has been observed between RFD and temperature ($R = 0.01$), possibly due to increase in soil moisture. Predictably, RFD during spring was much lower on average than that during winter.

Also, the radon activity concentration in the air of the basements of the radiochemical Department, located close to the experimental site, was measured. Radon activity concentration is determined by the operation mode of the inlet ventilation and did not correlate with C_{Rn} in the soil gas and RFD from the soil surface and is significantly higher than expected in some rooms.

Analysis of time series of radon activity concentration in outdoor air

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^{222}Rn (radon) is a ubiquitous trace component of the soil gas, from which it is released into the atmosphere. Radon activity concentration (RAC) in the surface layer of the atmosphere exhibits periodic diurnal variations; these variations depend on the intensity of solar radiation, wind speed and other meteorological parameters. Because radon has a well-defined source and is directly present in the atmosphere, it is considered a good indicator of atmospheric stability. In this study, the influence of solar radiation, wind speed and other meteorological parameters on RAC in the atmosphere is presented. Diurnal composites of RAC were approximated by the first two terms of Fourier series, and its parameters were compared against the intensity of solar radiation and the time elapsed from sunrise to sunset. It was also found that time lags of various lengths exist between the time series of RAC and those of meteorological variables.

Study of ^{222}Rn continuous monitoring time series and dose assessment in six European caves

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Public open caves are especially underground critical workplaces because of elevated ^{222}Rn activity concentration, in the order of kBq/m^3, frequently due to the absence of ventilation systems. People working in these places and also visitors are being subjected to high exposure to the noble gas and its daughters. Thus, caves constitute a special case for radiation protection in workplaces. The sources of ^{222}Rn irradiation in the underground caves are rock and clastic sediments, where the gas can seep into air, or water, and can travel along lengthy paths. The human health impact of the ^{222}Rn irradiation in caves can be evaluate using annual effective dose, which taking into account the time spent in this environment. The International Commission on Radiological Protection (ICRP, publication 137, 2017) provides a commonly used methodology to calculate the effective dose (mSv/y) from Radon and its progeny in underground caves. It is obtained by multiplying Radon activity concentration (Bq/m^3), time of human exposition (h/y) and dose coefficient (6.7×10^{-6} mSv/Bq h m^{-3}). The aim of the present contribution is focused on assessing the doses from ^{222}Rn monitoring data in seven European caves (located in Italy, Slovakia, Czech Republic and Slovenia), and also studying the influence of some monitored environmental factors. The ^{222}Rn activity concentration values show large diurnal and seasonal variations. Temperature is the main driving force of these variations. Consequently, also the dose values are very variable, but the average values for each monitored cave are high and not less than a few tens of mSv/y if workers with a residence time of 2 000 h/y (corresponding to 8 daily working hours) are considered. Detailed analyses of the results will be shown for each cave.

Radon variations and distribution in the typical family house in Slovakia

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The radon activity concentration (RAC) in the indoor atmosphere is not stable. As a rule in the indoor air the radon concentration is being changed in a relatively short time. For the monitoring of the RAC in indoor air of the typical family house the AlphaGUARD radon monitor and radon monitor on the basis of the scintillation chamber were used. All rooms in house were monitored. Room with the highest RAC was in contact with the subsoil. The average monthly values of RAC were in the range of 600–1600 Bq/m^3 during the year with maximum in summer and early autumn months and minimum in spring months. At the same time there were detected also significant daily variations of RAC in a wave shape with maximum predominantly in morning until noon hours and minimum in evening hours. The anticorrelation between the outdoor temperature and RAC wasn't observed. It is probably due to combination of air exchange rate in this house and time-dependent flow rate of soil radon into the building.

Radon exhalation rate measurement from granite samples

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Over the last four decades, special attention has been given to radon, ^{222}Rn, once it is the principal contributor to the radiation dose received by the population. Several studies provide conclusive evidence of the association between indoor radon exposure and lung cancer, even at the relatively low radon concentration commonly found in residential buildings [1].

Indoor exposure to ^{222}Rn radionuclide, resulting from radium ^{226}Ra, disintegration, represents a radiologic hazard and has been recognized as the principal natural source of public exposure in workplaces as well as in dwellings [2].

When radon gas escapes from the soil can enter inside the dwellings through cracks on the floor or by leaking through the walls. Additionally, radionuclides including particularly ^{226}Ra, can also be present in some building materials used for construction, being sources of indoor airborne radioactivity [3].

Radon exhalation mass rate measurements, from different granitic samples, were carried out using active measuring techniques with RAD7 detector. Differences about 86% in the radon exhalation rate were observed from one granite building material to another.

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