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THE HENRYK NIEWODNICZAŃSKI
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LABORATORY
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INSTITUTE OF NUCLEAR PHYSICS
Polish Academy of Sciences

BOOK of ABSTRACTS

III International Conference

RADON in the ENVIRONMENT

KRAKÓW, POLAND
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Foreword

We have a great pleasure to host you at the III International Conference **"Radon in the Environment 2019"** in our home city Kraków.

Since the year 2000 the Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences has been organizing serial conferences, traditionally called "Radon in the Environment". In 2000 and 2005 there were national conferences. This is the third international meeting; the previous ones took place in Zakopane (2009) and in Kraków (2015).

Research on natural radioactivity, including radon/thoron and its progeny has been conducted all over the world for many years. The conference is addressed to scientists of different specializations, medical doctors and others who work or are interested in natural radioactivity (focused especially on radon and thoron isotopes). We expect that this meeting will provide a forum to explore and discuss new scientific initiatives. European Union Council Directive 2013/59/Euratom laid down Basic Safety Standards (EU BSS) for protection against the dangers arising from exposure to ionising radiation. Under the new Directive radon takes on particular significance. Thus, we hope that our conference will be a helpful scientific meeting for all participants.

The conference will include oral and poster sessions. Apart from that we plan a new kind of a session. It is commonly known that the most interesting and fruitful part of each conference is short coffee break time. Thus, we propose one special session during which everybody will have possibility to individually ask or discuss subjects interesting for them with experts of different radon fields (there will be *Topic Tables* with "radon free" cup of tea or coffee). We hope that this session will also give you opportunity to start new cooperation, to learn something new about radon problems from each other.

In the frame of the conference the VII European Radon Association (ERA) Workshop will take place. The title of the ERA Workshop is "Radon measurements: calibration, quality assurance and measurement protocols" .

We wish you fruitful scientific discussions, but we also hope that you will find time to meet together in beautiful places in Krakow, not only to establish new cooperation but to make new friends as well.

Organizers

ORAL PRESENTATIONS

Invited Talk

IAEA SAFETY STANDARDS ON RADON IN DWELLINGS AND IN WORKPLACES

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In 2009, the International Commission on Radiological Protection (ICRP) published a statement on radon, recommending a revision to the upper value of the reference level for radon gas in dwellings, from that of ICRP's recommendations in 2007 with the value of 600 Bq/m^3 lowered to 300 Bq/m^3, and the International Atomic Energy Agency's (IAEA's) recent publication on General Safety Requirements, GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, setting the upper reference level to 300 Bq/m^3, the governments of IAEA Member States in Europe have achieved a lot of progress in the transposition of these requirements into the national legislative system.

The responsibilities of national competent authorities, among others, include arrangements to: collect data on the activity concentrations of radon in dwellings and other buildings with high occupancy by the public; provide information on exposure of the public due to radon and the associated health risks; and if the levels of radon are of concern for public health, to develop an action plan for controlling public exposure to radon. However, many meetings and interactions with the representatives of the IAEA Member States demonstrate lack of enforcement of the requirements on protection of the public against exposure due to radon at work and in dwellings.

In this regard, it is important to introduce an efficient system for enforcement of regulations, effective means of verification of compliance and a rigid system of public information and communication, in order to inform the population of the health risks from the exposure to radon indoors and the rights of the population to have a safe indoor environment both at work and in dwellings.

In 2015, the IAEA published a Specific Safety Guide (SSG-32) on Protection of the Public against Exposure Indoors due to Radon and Other Natural Sources of Radiation. This safety guide provides recommendations on how to meet the requirements for justification and for optimization of protection, by national authorities in control of natural sources of radiation indoors, on establishing of national radon action plans and development of a communication strategy. Further publications on radon mitigation and prevention methods, design and implementation of representative radon survey etc., are under development and will soon be made available to IAEA Member States.

During 2018 and 2019, a series of webinars were organised by the IAEA in cooperation with the World Health Organisation, the European Radon Association and Conference for Radiation Control Programme Directors (USA), on several different topics related to protection against radon. Several of the webinars were dedicated to sharing experience on national strategies for radon risk communication and involvement of specific target groups into radon risk communication and awareness campaigns.

Key words: Radon, radiation protection.

Invited Talk

SIGNIFICANCE OF THORON MEASUREMENT IN INDOOR ENVIRONMENT

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Exposure to radon, ^{222}Rn, is the most significant source of natural radiation to human being. It is an establish fact that exposure of high radon is one of the causative factors of human lung cancer. Although thoron, ^{220}Rn, has been a traditional object of study in atmospheric science but it has received relatively less attention than radon. The presence of thoron was often neglected because it was considered that the quantity of thoron in the environment is less than that of radon. However, recent studies have shown that the dose due to exposure to thoron and its progeny can equal or several times exceed that of radon and its progeny. Many studies found that thoron can be a significant contributor to the radiation dose in residential buildings. The results of radon, thoron and their progeny measurements in the houses of normal and high background radiation areas (HBRA) of India using both active and passive techniques in different types of houses are presented here.

A comparison between the results obtained with various techniques is also presented. The effectiveness of various thoron and progeny measurement techniques and their usefulness in estimating the dose to general public are discussed in details.

Invited Talk

HEALTH ASPECTS OF RADON

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An overview account is given both of the detrimental health effects of exposure to radon and its progeny and also of the beneficial health effects of radon arising from its extensive use in brachytherapy. Starting with descriptions of lung disease in medieval Bohemian underground silver miners the role of radon as a causative factor in lung cancer is traced to the present time.

Initially radon induced lung cancer was considered a health problem only for occupationally exposed underground miners but in the past half century it has been increasingly considered as a significant public health problem. In this context the main findings of some residential and occupational radon epidemiological studies are presented.

The physical processes involved in the deposition of airborne radon progeny in different parts of the human respiratory tract are described. In addition the essentials of lung dose models are presented. A short critical account of ICRP recommendations in recent years on radon exposure DCFs (dose conversion factors) is given . The latest recommendation of ICRP that the epidemiologically based dose conversion convention approach shall in the future be replaced by reference biokinetic and dosimetric models is discussed.

Invited Talk

RADON PROBLEM IN CONTEXT OF HOME ENERGY EFFICIENCY

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In the 21st century, humanity was confronted with the need for global energy savings and reduced energy consumption, which is associated with the following reasons. First, there is a shortage of hydrocarbons associated with the expected depletion of hydrocarbon deposits in the coming decades and the lack of a reliable alternative to coal, oil and gas. Secondly, the need to reduce the release of toxic pollutants formed during the combustion of fuels with high ash content into the environment. Thirdly, the need for a sharp reduction in greenhouse gas emissions, which are considered as one of the causes of climate change on the planet.

The housing and communal services are spheres with high consumption of energy resources. To ensure a comfortable living environment inside buildings, energy is consumed for lighting, heating, and other needs. In areas with a cold climate, buildings heating costs are very significant and make a crucial contribution to the overall energy consumption balance. In such countries, special requirements and regulation are established to save heat and reduce energy consumption in new and existing buildings as a part of the overall energy efficiency policy.

A number of architectural and technical solutions aimed at the heat saving have been developed in the construction industry. These include reducing the permeability of the building envelope by means of special coatings, installing PVC windows, organizing vestibules at the entrance and the fire escapes, and developing a building project that facilitate reducing of the heat loss. Architectural and construction solutions proposed up to date utilize the potential of two physical processes as follow: the thermal radiation of a building and the air exchange between the indoor and outdoor atmosphere.

The most important aspect of the heat saving measures for a radiation safety is the air exchange rate reduction in buildings, which occurs as a result of a number of reasons. The most common is an increase in resistance to fresh air entering the building. Despite the fact that during normal operation of the building, fresh air is supplied through specially equipped channels, these paths are controlled and activated by residents or building managers. For the majority of buildings in which energy-efficient measures have been implemented, either deactivation of the ventilation system or decrease in the ventilation rate during is typical.

Reducing the ventilation rate in energy-efficient buildings affects the entry and accumulation of radon, depending on the mechanisms of the radon transport in the building (convection or diffusion). Under the diffusion domination, the accumulation of radon increases in the situation of ventilation system deactivation. More complex situations can occur with convection transport.

In various countries of the world, a number of examples have been obtained of how energy-efficient technologies in construction lead to a significant increase in the radon concentration in certain homes and a relative increase in the average levels of radon concentration in the region. In general, there is a situation of permanent increase in population radon exposure, which disagrees with the optimization principle.

Reducing radon accumulation in energy efficient buildings requires special approaches based on an understanding of the physical processes underlying this phenomenon.

A01

RADON LEGISLATION – CHALLENGES OF IMPLEMENTATION

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Based on the Directive 2013/59/EURATOM the Member States of the European Union had to develop new radon protection regulations. Most obligatory is the measurement of radon at workplaces in radon prone areas and the (where necessary) subsequent need for reduction of radon concentrations. Radon save construction of new buildings is an additional obligation.

Thousands of employers in Europe have or will have to meet this obligation now and in the years to come. The communication of this duty is one big challenge for the responsible administrative bodies in the member states. As a consequence there will be a high demand for measurement devices and subsequently for trained personal technical construction measures to reduce radon concentrations in buildings.

Another big challenge for the administration is and will be the support of the concerned employers. There is a need for information as well as for financial support that should be met adequately. National funding programs should be considered and possibilities to get also European funding should be searched for.

In Germany this process has started. The efforts of the Free State of Saxony to find support for employers as well as for private persons will be presented. Additionally measures to inform the public and to train consultants and crafts persons will be mentioned.

Ref.

[1] www.radon.sachsen.de

[2] Directive 2013/59/Euratom

[3] Radonmassnahmenplan Deutschland

A02

ACTIVITES AT THE INTERNATIONAL LEVEL TO CONTROL RADON EXPOSURE

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With the classification of radon as a carcinogen by IARC/WHO in 1988 the efforts of national authorities and international organisations to control radon increased significantly.

Driven to a large extend by the new international (IAEA) and European (EU) Basic Safety Standards, the activities to control radon were further intensified over the last years. IAEA started to provide training and financial support to its member countries for setting up a national radon programme; EU countries need to implement the Directive which is quite a challenge to the national authorities in many countries; WHO set a milestone by editing the WHO Radon Handbook; multiple reasearch activities were started (RADPAR, MetroRADON, SmartRADON, LIFE-RESPIRE etc.); ISO standards for radon metrology were developed; national and international radon associations were founded; new and exisiting companies for measurement and mitigation widen the spectrum of radon instruments and get ready for the increasing market opportunities.

This presentation will give an overview of the various efforts by international organisations, the scientific community, and by international associations.

A03

ARE RPA, IDENTIFIED ON SURVEY IN DWELLINGS, REPRESENTATIVE OF RADON LEVELS IN WORKPLACES?

Rosabianca Trevisi[1], Federica Leonardi[1], Silvia Bucci[2], Giorgia Cinelli[3], Valeria Gruber[4], Josè Gutierrez Villanueva[5], Thomas Heinrich[6] and Peter Bossew[7]

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Typically, radon priority areas (RPA) are identified on the basis of surveys carried out in dwellings: indeed, indoor radon surveys in workplaces are scarce and - usually - mainly restricted to specific workplaces (such as schools).

Dwellings seem more suitable than workplaces to represent indoor radon distribution (less internal variability, more constant usages modality).

However, some studies, comparing distribution of radon values in workplaces and in dwellings on national scale, evidenced that not always the results coming from surveys performed in dwellings reflect actual situation in workplaces. This bias could be an issue considering that recently, international/national regulations introduce specific requirements to control radon exposure in workplaces located within such areas (e.g. Basic Safety Standards Directive [1]).

The present study, carried out in the framework of MetroRADON project [2], is aimed to reanalyze data collected in surveys on mixed samples (workplaces and dwellings) carried out in some European countries, in order to compare the results and find correlations of the distributions of indoor radon levels both in workplaces and in dwellings.

Moreover, in order to elaborate a model that could be predictive of the direction in which radon levels in workplaces and dwellings could diverge, a collection of information about the building characteristics (ventilation, building materials, building typology, dimension, etc.) and occupancy time is ongoing.

Preliminary results are shown here.

Ref.

[1] European Union (2013), Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom, Official Journal of the European Union OJ L13, 17.1.2014, p. 1 – 73, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L:2014:013:TOC

[2] MetroRADON (16ENV10) is 3-years research project on metrology for radon monitoring granted by the European Metrology Programme for Innovation and Research (EMPIR): http://metroradon.eu/

A04

AN INTRODUCTION TO THE METRORADON PROJECT – METROLOGY FOR RADON MONITORING

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The European Council directive 2013/59/EURATOM (EU-BSS) evokes new challenges for metrology of radon measurements and calibrations in Europe. The legal implementation of the EU-BSS requires a metrologically sound basis of radon protection for European citizens.

The objective of the ongoing MetroRADON project is to enable SI traceable monitoring of radon (^{222}Rn) at low radon activity concentrations (< 300 Bq/m³) including calibration procedures with acceptably low uncertainties and radon mapping. These objectives include the investigation of the influence of thoron (^{220}Rn), the harmonisation of radon measurements and the development of new methodologies for the identification and characterisation of radon priority areas in Europe. The project will provide SI traceable metrological resources (calibration and measurement) for the monitoring of radon, which essentially facilitate the harmonised implementation of the new EU-BSS in Europe.

The methods developed in the project will assist EU member states in the establishment of their national radon action plan, which is required under the EU-BSS. Guidelines and recommendations on the new calibration and measurement procedures will be published. Traceability of European radon calibration facilities using the new procedures and novel reference sources will be evaluated and the project partners will ensure that the results of this project will be taken up by end users, standards organisations, regulators and international bodies and associations.

MetroRADON is funded by the European Metrology Programme for Innovation and Research (EMPIR) as a Joint Research Project (JRP). The JRP runs from June 2017 to May 2020 with 17 European partner organisations (metrology and research institutes).

The contribution will provide an overview of the partners, goals, first results and impact of the MetroRADON project.

A05

RESULTS OF ANALYSIS OF METRORADON QUESTIONNAIRE DATA ON INDOOR RADON SURVEYS

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One of the specific objects of MetroRADON project [1] is to compare existing radon measurement procedures in different European countries and use the results to improve the consistency of indoor radon measurements across Europe.

For this purpose, a questionnaire was developed to collect information on indoor radon surveys in order to:

a) identify the rationale and methodologies used;

b) identify the extent and possible sources of inconsistencies in the results of indoor radon surveys;

c) propose approaches for reducing inconsistencies and improve harmonisation of indoor radon data;

Moreover, some information have been collected about how EU Member States intend to transpose (or have transposed) the latest Basic Safety Standards Directive [2] into national law.

The questionnaire has been addressed to all European institutions working in this field (not only national authorities but also regional administrations, universities, research centres). They have been invited to complete a separate questionnaire for each survey. Between December 2017 and July 2018, a total of 56 questionnaire forms on indoor radon surveys were completed and returned by universities, research institutions and competent authorities on national and regional surveys from 24 European countries. In this work, results from the analysis of replies to the questionnaire will be presented, highlighting similarities and differences on radon survey methodologies across Europe.

Ref.

[1] MetroRADON (16ENV10) is 3-years research project on metrology for radon monitoring granted by the European Metrology Programme for Innovation and Research (EMPIR): http://metroradon.eu/

[2] European Union (2013), Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom, Official Journal of the European Union OJ L13, 17.1.2014, p. 1 – 73, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L:2014:013:TOC

A06

NATIONAL INDOOR RADON SURVEYS PERFORMED IN EUROPE: A QUALITATIVE OVERVIEW

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Radon is identified as the second cause of lung cancer after smoking, being responsible for between 3% and 14% of all lung cancers [1]. Due to its importance, in 2013, European Union laid down Basic Safety Standards (BSS) for protection against the ionizing radiation, including exposure to radon [2]. The BSS directive obliged all European Union member states to establish a radon action plan and to inform public about their radon. Similarly, for non-EU member states, International Atomic Energy Agency within their BSS, require radon surveys and provide guidelines how to perform them [3]. This initiated national surveys in several countries for the first time or repetition of the existing ones.

Recently, in the framework of MetroRADON project (EMPIR, JRP-Contract 16ENV10) a JRC report on literature review on indoor radon surveys performed in Europe was given [4].

The aim of this contribution is to give qualitative overview of national surveys performed in European countries, based on the data extracted from JRC report. The special attention is given on the qualitative and conceptual description of surveys their representativeness, sampling strategies and measurement techniques and quality assurance and quality control (QA/QC).

The literature survey has shown that methodologies used in surveys are very diverse and practically it is impossible to find two completely the same ones. The discussion of representativeness of performed is very sparse and if existing, usually incomplete. This makes difficult to compare two surveys and compile the data. In order to accomplish uniform results at the international level it is therefore important to provide that quality assurance programme, the harmonization of criteria, sampling procedures, calculations and the reporting of results, agreed on the basis of fundamental principles and international standards.

Ref.

[1] World Health Organisation, Handbook on Indoor Radon, WHO, Geneva, 2009.

[2] European Union, Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom, Official Journal of the European Union OJ L13, 17.1.2014, p. 1 – 73

[3] IAEA (International Atomic Energy Agency), 2011. Radiation protection and safety of radiation sources: International basic safety standards Interim edition. General safety requirements Part 3

[4] Pantelić, G., Čeliković, I., Živanović, M., Vukanac, I., Nikolić, J., Cinelli, G., Gruber, V., 2018. Literature review of Indoor radon surveys in Europe. EUR 29613 EN, Publications Office of the European Union, Luxembourg.

A07

EXTREME REVERSE SEASONAL VARIATIONS OF INDOOR RADON CONCENTRATION: A CASE STUDY

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Indoor radon concentration follows usually a seasonal cycle with higher levels in cooler months and lower levels in warmer months. This cycle depends mainly on temperature and weather conditions of the area (i.e. changes in the atmospheric parameters reflecting of chimney effect and wind effect), with higher radon concentration variations between cooler and warmer months in areas where temperature in winter months is lower (e.g. [1]).

However, the *average* effect is modified by *individual* parameters such as living habits (i.e. changes in the house's ventilation rate), occupancy pattern, and building characteristics, thus resulting in different seasonal variations among dwellings in the same area, including some cases where radon concentration in warm months result to be higher than radon concentration in cold months. These situations are usually referred to as situations with *inverse* seasonal variations of indoor radon concentration (e.g. [1–2]).

Reverse seasonal variations can give rise to significant underestimation of the actual annual average of radon concentration when a measurement shorter than one year is performed, e.g. in winter season, and an average seasonal correction factor is applied for estimating annual average.

In addition to the inverse seasonal variations described above, some *extreme* inverse seasonal variation can occour in specific situations. Such situations have been identified in the framework of a study on long-term variations carried out in some tenths of dweellings in Rome and surrounding small towns. In particular two dwellings with high reverse seasonal variability were identified in a small town near Rome, on the basis of six-month measurements carried out for several years by passive devices containing solid-state nuclear detectors. In one of these dwellings radon concentration was monitored also by a continuous radon monitors, showing extreme and very rapid increases of radon concentration during warm months. In this presentation, results of both passive and active measurements of radon concentration will be presented and compared with other situations with extreme inverse seasonal variations found elsewhere (e.g. [3]–[4]).

Ref.

[1] [1] Bochicchio F., Campos-Venuti G., Piermattei S., Nuccetelli C., Risica S., Tommasino L., Torri G., et al. Annual average and seasonal variations of residential radon concentration for all the Italian Regions. Radiation Measurements 40(2005)2–6, pp. 686–694.

[2] [2] Friedmann H. Final results of the Austrian Radon Project. Health Physics 89(2005)4, pp.339–348.

[3] [3] Moreno V., Bach J., Baixeras C., Font L. Characterization of blowholes as radon and thoron sources in the volcanic region of La Garrotxa, Spain. Radiation Measurements 44(2009)9–10, pp.929–933.

[4] [4] Wilson D.L., Gammage R.B., Dudney C.S., Saultz R.J. Summertime elevation of 222Rn levels in Huntsville, Alabama. Health Physics 60(1991)2, pp.189–197.

A08

APPLICATION OF TLD DEVICES FOR RADON AND THORON PAEC MEASUREMENTS IN AIR - *IS THE CONCEPT OF "TOTAL" PAEC USEFUL?*

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The calibration of radon decay products monitors is a difficult task, while in case of thoron decay products it is even a bigger problem A lack of a primary standards of radon decay products or thoron decay products is an important issue.Since many years measurements of potential alpha energy concentration (PAEC) are done with application of special devices, called ALFA probes, with thermo-luminescent detectors (TLD). The readout of TL detector shows directly potential alpha energy, with no dependence on equilibrium factor etc. This technique, which had been used only for radon decay products measurements, we try to modify to allow simultaneous measurements of radon and thoron PAEC.

The idea is to apply two sets of TL detectors in the same device during and after sampling. The first set of detectors is used to store the energy of alpha particles during sampling till 5 hours after sampling. Due to that procedure, the first set of TLD should contain the whole PAEC energy of radon decay product and part of PAEC of thoron decay product. After that, the first set of TLD is replaced with the second one, left over the filter for another 55 hours. This set should contain only the PAEC from thoron decay product. Taking into consideration timing it would be necessary to subtract the part of PAEC from the first result and add it to the second.

The problem is that during underground or field monitoring it would be difficult to make such a procedure. Therefore another approach is possible. To leave the device for 60 hours after sampling without any changes and the readout of the TL detectors will give the "total" PAEC, being a sum of radon and thoron PAECs. The question is if such a value has any meaning for the dose assessment?

A09

ASSESSING INDOOR RADON LEVELS USING A SCALE MODEL ROOM

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In the frame of RESPIRE (Radon rEal time monitoring System and Proactive Indoor Remediation), a LIFE 2016 project funded by European Commission, the contribution of building materials of volcanic origin to indoor radon concentration was investigated.

^{222}Rn and ^{220}Rn exhalation rates of main building materials used in Caprarola town (central Italy) were measured using an accumulation chamber connected in a closed-loop with a RAD7 radon monitor. Among others, "Tufo di Gallese" ignimbrite provided the highest values: 5.90 ± 0.10 Bq m^{-2} h^{-1} for ^{222}Rn and 6400 ± 500 Bq m^{-2} h^{-1} for ^{220}Rn. This material was then used to construct a scale model room of 62 cm x 50 cm x 35 cm (inner length x width x height) to assess experimental radon and thoron activity concentration at equilibrium and study the effect of climatic conditions and different coatings on radon levels.

The first test was carried out at 20 - 25 °C to determine experimental ^{222}Rn and ^{220}Rn equilibrium activities in the model room, not covered with plaster or other coating material. Values much lower than theoretical equilibrium were recorded in just two days demonstrating that the room "breaths", exchanging air with the outdoor environment. A second test was performed after sealing the external faces of the room with a transparent film used to conserve food. This way, equilibrium activities of ^{222}Rn and ^{220}Rn, achieved in about 100 hours, reached 11,000 and 500 Bq m^{-3}, respectively, showing that an outer cover strongly limit the inner air dilution through the very porous ignimbrite (43 %). A third experiment with a longer duration (19 days) clearly evidenced that ambient temperature strongly influence exhalation rates. A decrease of 7 °C produced a 15 % reduction of radon levels in the experimental circuit.

After that, inner walls of the room were covered with radon-free plasterboard to investigate if internal shields could reduce indoor radon. This test showed no effect on ^{222}Rn, but a halving of ^{220}Rn concentration, due to the slow-down of diffusion through the drywall. Afterwards, a double coat of a simple thermal insulation paint was applied on the plasterboard. Indoor ^{220}Rn was not detected and ^{222}Rn was significantly decreased, demonstrating that the combination of plaster and paint affects the gas permeability of the walls. Finally, a waterproofing paint was added over the previous one, resulting in a further fall of ^{222}Rn level. When the transparent film covering the external faces of the walls was removed, ^{222}Rn was reduced at one tenth of its value.

This dataset demonstrate that air exchange with outdoor environment is really effective to cut indoor radon levels, while inner covers (such as plasterboard and different kind of paints) only partially works on ^{222}Rn, but entirely on the short-lived ^{220}Rn. Finally, low temperature furtherly reduce radon exhalation from building material and, in turn, indoor activity concentration.

A10

EXPERIMENTAL EVALUATION OF AGEING AND FADING EFFECTS OVER 3, 6, AND 12 MONTHS FOR THREE RADON CONCENTRATION MEASUREMENT TECHNIQUES BASED ON NUCLEAR TRACK DETECTORS

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Evaluation of the annual average radon concentrations in dwellings and workplaces, as required by the recent international regulations, is commonly performed using techniques based on passive devices containing nuclear track detectors and tracks read-out systems. These techniques could be affected by ageing of the detector material and fading of the tracks, whose net effect is a detector sensitivity reduction [1].

Therefore, an experimental study was carried out in order to evaluate ageing and fading effects in typical indoor environments for three different techniques used in our laboratory: i) two devices based on CR-39 materials produced by different suppliers (i.e., *Intercast Spa* and *Radosys Ltd*) with two different fully automated image analysis systems used for tracks counting; ii) a device based on LR 115 as detector material whose tracks are counted with a spark counter. The study was designed to evaluate ageing and fading for exposure periods of 3, 6, and 12 months using AlphaGUARD active monitors as reference detectors. This study represents an extension of a previous one – limited to two of the three techniques considered in this study – aimed to evaluate ageing and fading effects for measurement period of 12 months only [2].

The results show that ageing and fading do not significantly affect the response of the technique based on LR 115 detectors, whereas an underestimation of the actual radon exposure was found for the two techniques based on CR-39 detectors. In particular, measurements performed over a single period of 12 months have a sensitivity reduction of about 10% and 20%, for techniques based on CR-39 *Intercast Spa* and *Radosys Ltd,* respectively.

Ref.

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A11

HIGH-RESOLUTION MAPPING OF THE GEOGENIC RADON POTENTIAL 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. One possibility to this end is using the geogenic Rn potential (GRP), which quantifies availability of geogenic Rn for infiltration into buildings. It is defined as a function of Rn concentration in soil gas and soil gas permeability.

Current GRP maps rely on various geostatistical approaches (Collocated Cokriging, Regression Kriging, Gaussian Simulation etc.) considering selected co-variates (e.g. geology, uranium concentration in soil). However, the processes of generation, release, transport and exhalation of Rn is known to be extremely complex resulting in high spatial and temporal variability. Due to its complexity, the utilization of more environmental co-variates seems to be promising for improving GRP prediction accuracy.

In this study, we use ~ 4,000 point measurements of soil gas Rn concentration and soil gas permeability across Germany in combination with >100 environmental co-variates (predictors) for building machine learning models (ML). The ML algorithm MARS (Multivariate adaptive regression splines) can deal with numerical and categorical predictors simultaneously. Potential candidate predictors comprise geological units, hydrogeological units, soil type units, soil grain size distribution, soil hydraulic properties, soil moisture data, tectonic fault data, radionuclide concentration in topsoil and geomorphological parameters.

The final MARS model for estimating soil gas Rn concentration includes 17 informative predictors. The most important ones are geological and hydrogeological unit, top soil silt content, uranium concentration in top soil and soil landscape unit. For predicting soil gas permeability 11 informative predictors were selected with geological and hydrogeological unit, geomorphological parameters (elevation, slope, SAGA Wetness Index) and parameters describing the hydraulic conductivity curve being the most informative.

The results of the MARS model will be compared with other machine algorithms such as artificial neural networks or random forests. The proposed approach will allow a higher spatial resolution of the GRP map (at least 2 km) than achieved so far with simpler methods (10 km). This is possible because the output resolution depends on the spatial resolution of the relevant predictors rather than on measurement density of one set of point measurements only, as done so far.

A12

DEVELOPMENT OF A GEOGENIC RADON HAZARD INDEX

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Indoor radon (Rn) is acknowledged a serious hazard to health, being the second most important cause of lung cancer after smoking. Indoor Rn mapping aims to support identifying Rn priority areas, i.e. primary focus areas for Rn exposure mitigation. The European Basic Safety Standards Directive, which forms the framework of European Rn regulation, requires all EU Member States to delineate radon priority areas (RPA). However, due to different definition between countries, RPAs are generally not consistent across borders.

In parallel, a European Atlas of Natural Radioactivity has been developed by the JRC of the EC, which foresees including a map of geogenic Rn availability, quantified by a variable still to be defined. The Geogenic Radon Hazard Index (GRHI) is conceived as quantity that measures the contribution of geogenic Rn to exposure and hence risk. The GRHI concept was first proposed in 2014, and several attempts have since been made to develop a viable model. All existing models rely on association between geogenic factors and building weighted combinations between available quantities.

The GRHI can be defined as a numerical or ordinal-categorical quantity, i.e. ordered classes. The GRHI should be applicable universally, i.e. it should be possible to derive it from whatever geogenic data are regionally available. It should also be consistent in the sense that derivation from different datasets should yield the same result. This implies uniformity across borders of regions in which different predictors are available, given the same objective geogenic control. In European countries, different databases are available, which are physically and statistically related to the geogenic radon potential (GRP). These include geology, soil properties, hydrogeology, tectonics and seismicity, geochemistry, gamma dose rate, soil gas and standardized indoor Rn concentrations and GRP of different definitions. The GRHI would thus constitute a harmonized measure which integrates different types of data. As a top-down harmonization method, it utilises whatever data are available, contrary to a bottom-up approach which would require harmonized input data. The latter is evidently not realistic for the foreseeable future, since it would require Europe wide dense harmonized sampling. Tasks include the application of confirmatory (regression, ANOVA) or exploratory (PCA and similar) statistical techniques, also including spatial information.

In this contribution, we present existing approaches and discuss their relative advantages andshortcomings. Recent advances are shown and examples given. Once a GRHI definition is developed, it could constitute a possible database for a Europe wide map of RPAs. The GRHI could thus be a harmonized measure of the degree of radon priority of an area or a given location.

A13

CHALLENGES OCCURRING BETWEEN GEOGENIC RADON AND RADON MITIGATION

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In the framework of the last Council Directive 2013/59 [1] laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation, the problem of radon was assumed in Romania at national level by responsible authorities through the design and development of a National Radon Action Plan and an adequate legislation [2]. In order to identify radon risk areas, however, it is necessary to perform systematic radon measurements in different environmental media (soil gas, water, indoor air). Indoor radon is strongly influenced by the geological characteristics of the bedrock. However, accumulation, transport and entrance paths are defined by other factors such as permeability, ventilation, occupation, etc. This paper presents the results of 100 radon diagnostics of building sites which brought forward some of the most important challenges radon mitigators are faced with every day. The results can be a useful tool to implement radon policies at both the national and local levels, defining priority areas for further study when land-use decisions must be made.

Ref.

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Acknowledgements

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A14

Ground Heat Exchangers (GHEs) and indoor radon

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Ground Heat Exchangers (GHE) are increasingly used in private homes and institutions. In Poland, many companies are involved in the production and installation of these heat exchangers. Estimated number of GHE installations in Poland is 150 000.

However, both homeowners and GHE producers are usually not aware of the possible danger of radon. In the case of open GHEs, indoor radon concentration can increase significantly during GHE operation.

The first results of radon measurements in houses with installed GHE are presented. The measurements were made both during the GHE operation and when it is switched off. The differences in indoor radon concentration levels are visible.

LER IFJ PAN has started cooperation with GHE producers and will carry out wider research aimed at improving the heat exchanger, so as to reduce the risk of introducing radon into the house. The first proposals for such modules have alreay been developed and are being tested.

A15

COMBINED ANALYSIS OF STUDIES ON THE LUNG CANCER ASSOCIATION WITH INDOOR RADON EXPOSURE

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The performed analysis included results of a number of studies on the radon exposure effects to human health. Both case-control studies and ecological design studies of aggregated territorial-based medical statistical data and were considered.

Analysis of geographically aggregated data on the lung cancer mortality and indoor radon concentration showed that the use of actual data on the prevalence of smoking and infection with human papilloma virus, as co-factors of the lung cancer risk, increases the reliability and consistency of estimates of the radiation risk associated with radon exposure. The analysis was made for Russia (by oblasts) and the United States (by counties) for which there are reliable data on cancer mortality and radon survey by administrative regions. The estimates of excess relative risk of lung cancer due to radon exposure obtained for US and Russian males are 0.08±0.04 and 0.01±0.03 and for females 0.11±0.07 and 0.36±0.15 per 100 Bq/m^3 (with 90% confidence interval), respectively.

Within the framework of the meta-analysis, data on 31 case-control studies of the dependence of lung cancer on radon exposure in dwellings were collected. These studies were conducted in 13 countries in Europe (19 studies), North America (9 studies) and Asia (3 studies). The collected data set included 20,703 cases and 34,518 controls. According to the meta-analysis performed applying statistical weighting depending on the size of the study and quality of indoor radon exposure assessment, the linear non-threshold model satisfactorily fits the exposure-effect relationship in the entire range of indoor radon concentration and the observed lung cancer risk is statistically significant in the case of exposure to radon during 30 years with the radon concentration above 100 Bq/m^3. The slope factor of linear non-threshold exposure-effect relationship is 0.14 (90% CI 0.09-0.19) per 100 Bq/m^3.

Thus, different types of epidemiological studies and analysis of medical and radiation-hygienic statistics on lung cancer mortality and the results of radon surveys provide consistent estimates of the lung cancer risk due to indoor radon exposure. The combined analysis has reduced the uncertainty in the evaluation of the excess relative risk of radon induced lung cancer. The value obtained after combining the results of ecological studies and meta-analysis is 0.14 (90% CI 0.10–0.18) per 100 Bq/m^3.

A16

CHARACTERISING URBAN POLLUTION VARIABILITY IN CENTRAL POLAND USING RADON-222

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The adverse health effects of aerosols and gaseous anthropogenic emissions are well known. Since rates of emission in urban regions scale with population, it is important to improve understanding of concentration variability in the "zone of habitation" to assess health risks and the suitability of emission guidelines. This study utilizes a recently-developed Radon-222 based tool for classifying stability to characterize the degree of influence the atmospheric mixing state has on pollutant concentration variability in an urban region of central Poland.

To assess atmospheric influences on temporal (diurnal and seasonal) pollution variability we employ 4-years of meteorological, radon, trace gas (NO, NO_2, CO, SO_2), and aerosol ($PM_{2.5}$ & PM_{10}) observations in the suburb of Zgierz. After removing periods of synoptic non-stationarity, the stability classification technique is used to assign all observations (in whole-day blocks) to one of four atmospheric mixing categories. Mean wind speeds increased by more than a factor of two from the most stable to well-mixed nocturnal conditions, which reduced near-surface nocturnal radon accumulation by a factor of five.

A strong seasonality in NO_x and CO concentrations was observed, contributed to by changing atmospheric mixing depths (day and night) and additional cold-season combustion sources. Peak daily NO concentrations increased by a factor of 2-4 from well-mixed to stable conditions, but changes were smaller in the case of NO_2 and CO (factor of 1.5-2). Aerosol concentrations were typically highest at morning peak commute times, and increased by a factor of 2 under stable conditions.

Air quality for the region was typically best in the afternoons, when the boundary layer was deepest, but also improved in the 3-4 hours after midnight due to advection of cleaner air from outside the city. Changing influences on air quality at the site were attributed to specific regions of the Łódź agglomeration to the south, but the topographic setting of the monitoring site also played an important role. Emissions from the Łódź central business district were often brought to the site in katabatic flows when gradient winds were light and from the south.

Observed daytime CO concentrations in summer were entirely attributable to vehicle emissions, whereas an additional daytime source of around 48 mg m^{-2} h^{-1} in winter was attributed to combustion for heating. Winter CO concentrations attributable to local domestic combustion were estimated to be up to a factor of three less than the CO being advected to this region from upwind European source regions.

A17

ASSESSMENT OF THE IMPACT OF CLIMATE PARAMETERS ON THE RADON TIME SERIES MEASURED INDOOR, OUTDOOR AND IN SOIL

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Series of radon concentration and ambient parameters were monitored at hourly intervals in five measurement points on the campus of the QST in Chiba: 1) a rarely-visited partially-subterranean store-room in a public-service building, 2) two rarely-visited rooms on ground and first floor of a currently not used office building 3) outdoor and 4) in soil at 0.7 m depth. The distance between measurements points were not more than 150 m. Due to the different start date of sampling at each location, the simultaneous sampling period for all points totalled 1000 days.

We derived mean daily, monthly and annual radon concentrations and the same statistics for the associated meteorological data.

The statistical evaluation of these parameters shows the correlation between temporal variations of radon concentration and meteorological parameters. Since the rooms (1 and 2) are little visited, there is little influence of usage patterns, leaving geogenic, meteorological and building-specific factors and their interaction as sources of Rn variability.

Although not typical for dwellings, the results of radon time-series analysis can be used to derive correction factors for radon concentration in Japanese indoor environments due to seasonal variation of climatic parameters as well as for determination of the influence of measurement time to the uncertainty of the estimated long-tern mean.

A18

STATUS OF RADON-IN-WATER MEASUREMENTS IN EUROPE: CONCLUSIONS FROM AN EC-JRC EUROPEAN-WIDE PROFICIENCY TESTS

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A European wide proficiency test (PT) on measurements of the massic activity of ^{222}Rn in drinking water was organised by JRC-Geel in 2018. One hundred one European laboratories that are in charge of monitoring environmental radioactivity participated. The proficiency test materials with elevated ^{222}Rn massic activity were collected at a remote location in Austria.

A key problem when measuring an inert gas is the possibility of losing some of it during handling. Extra efforts were made to secure ^{222}Rn tightness throughout the whole process from sampling until measurement [1], which also had been tested in a small scale pilot-PT [2]. The packaging and transport chain had to be established in a timely manner with short storage and delivery times. The process involved using all state-of-the art knowledge regarding sampling and transporting ^{222}Rn in water such as temperature controlled transport and use of radon tight containers. During the PT, two independent standard measurement methods (gamma-ray spectrometry and liquid scintillation counting) were used for the reference value determination, homogeneity and short term stability studies. Homogeneity studies confirmed that the massic activity of ^{222}Rn at the sampling-sites did not show any significant change over the sampling period. The reference values were calculated from the power moderated means of measurement results at JRC-Geel. The uncertainty of the reference values and incorporated the uncertainties from stability, between-bottle homogeneity and characterization studies [3].

The performance of the participating laboratories was evaluated with comparing to the reference value using relative deviations, z-score, zeta-score and E_n-number [4]. It was found that the 75% of the participants' results were within the ± 15 % reference range and the general performance was acceptable. One can discern a small negative bias in the results which is most likely due to loss on radon when handling the sample, e.g. when transferring it to measurement containers.

When the uncertainty budget was evaluated then the same numbers of acceptable scores were found with 75%. The results were also evaluated on the basis of applied methods to check for method dependency (gamma-ray spectrometry, liquid scintillation counting and emanometry). Each of the applied methods seems to be adequate for radon-in-water measurements. A key observation is that radon loss is not perfectly taken care of in all laboratories and it should at least be included in the uncertainty budget.

Ref.

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A19

TRACEABLE CALIBRATIONS OF INSTRUMENTS MEASURING RADON ACTIVITY CONCENTRATION

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With regard to the protection against exposures to radon (222Rn) at home and at work, the transfer of the European Council Directive 2013/59/EURATOM into national legislation requires a reliable metrological basis that ensures confidence in measurements. The EMPIR research project Metrology for Radon is dedicated to this requirement aiming at developing novel procedures for the traceable calibration of radon measurement instruments at low activity concentrations (100 Bq/m^3 to 300 Bq/m^3) with relative uncertainties ≤ 5 % (k=1).

In the framework of the EMPIR research project, a facility for radon reference facility has been set up at the German Federal Office for Radiation Protection (BfS). Its basic component is a radon-tight chamber with a certified volume traced back to a standard volume at PTB. The radon activity concentration is established by adding a known radon activity provided by a gas standard. The facility is equipped with instruments for monitoring temperature and air pressure. This basic setup is extended by an additional volume as well as by devices for monitoring online the actual radon activity concentration.

The facility is used to fulfill different measurement tasks, and to improve the traceability of the measurement quantity on a high metrological level. The quantity radon activity concentration can be provided with uncertainties of less than 5 % (k=1) even in the target range between 100 Bq/m^3 to 300 Bq/m^3.

By dissemination of the quantity radon activity concentration to external interests, it will contribute towards international harmonization and comparability of radon measurements.

A20

QUALITY ASSURANCE IN RADON SSNTD MEASUREMENTS – PHE EXPERIENCE

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Solid state nuclear track detectors (SSNTD), particularly poly-allyl diglycol carbonate polymer have a long history of application in measurements of radon. Although, it is relatively easy to set up and run measurement facilities, but to obtain precise and accurate results may be not a trivial and quite challenging task.

Over 40 years ago PHE has established radon measurements laboratory to deliver services for radon measurements at homes and workplaces in the UK [1]. The key factor in developing these services was to set up a stringent quality control and assurance protocols to enable delivery of reliable and accurate results. There are nearly 40 check points in the process, starting from quality check of PADC polymer ending up with result delivery that includes correction factors. This constitutes the objective of this work that aims to show how to obtain reliable results in radon measurements.

The study shows that by applying appropriate quality controls much better-quality result data are obtained. Moreover, further improvement was achieved by additional, special controls procedures and data manipulation algorithms such as single PADC sheet calibration, correction factors to include aging/fading effects, exposure linearity correction or introduction of the threshold point between nuclear track and area based calculations [2,3]. Examples of distinctive applications of SSNTD detectors in measurements of outdoor radon and radon in harsh environments will be presented.

In conclusion, radon measurements can be greatly improved by introduction of quality controls during detector production/assembly stage as well as in the final stage of data processing. Low level radon measurements (outdoor radon) and non-standard measurements prove the significance of such approach. It also allows not only to improve standard measurements, but to expand practical application of radon measurements in broader fields.

Ref.

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A21

PRODUCTION OF STANDARD RADON IN WATER SOLUTION AND COMPARISON OF DIFFERENT MEASUREMENT METHODS FOR ACTIVITY DETERMINATION.

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Good measurement of radon concentration in tap water and natural springs is an important issue both for human health protection and for geological studies.

For this reason the European Joint Research Center promoted a Radioactivity Environmental Monitoring Proficiency Test for radon in water measurement, that was held in October 2018 [1].

ENEA INMRI developed a radon in water standard generator to provide reference solution for the calibration of measurement system such as "aqua kit" of commercial radon monitors, HPGe gamma spectrometry system (GSS) and liquid scintillation counter (LSC).

The circuit is a closed loop connecting a two litre glass bottle containing the radon source, a glass bubbler, the circulation pump and a special dispenser to fill vials for LSC. A Marinelli beaker and other vessel may be added to the circuit according to the needs of the customers. Radon source is provided by Eurostandard (CZ) and consist of ^{226}Ra incorporated in resin, ^{222}Rn diffuses in the resin while Radium is trapped and does not contaminate the water.

The aim of the circuit is to provide a set of water samples, all with the same radon concentration, to be measured by different measuring systems, without leakage of radon.

The reference value of radon in water activity is measured in the primary radon standard operating at ENEA INMRI with 2% combined uncertainty [2] .

The water samples, with certified radon concentration, are dispatched to the costumers for the calibration of their instruments. In the actual configuration the generator may produce more than 1.5 L of radon enriched water in glass bottles and 350 cm^3 of water for LSC measurement.

Several LSC measurements were performed at ENEA with Quantulus with and without $\alpha - \beta$ separation techniques, repeatability of the result is better than 1%.

Five series of gamma spectrometry measurement were carried out with Ortec instrument, water sample was placed in 570 cm^3 glass bottle; two different bottle was measured in every experiment to check the reliability of the sampling procedure. Repeatability of results is within 3% and in every experiment the activity of the two bottles was the same within 0.4%.

Preliminary test for absolute measurement of radon concentration with LSC using triple to double coincidence ratio technique are ongoing.

Results achieved prove that the radon in water generator is suitable for the production of reference solution for calibration purpose.

Ref.

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A22

RADON MEASUREMENTS IN BIG BUILDINGS

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The recently passed Radiation Protection Law in Germany deals for the first time at the legislative level with measures to protect against radon at workplaces and in public buildings.

Many jobs are in big buildings. In contrast to small buildings, there is no measurement protocol for big buildings that makes it possible to assess the radon situation of the building reliably and without much effort. According to the European Consortium for the Measurement of Radon in Big Buildings (RiBiBui) can such a measurement protocol be developed with research in the areas of fundamentals, simulations as well as experiments and data analysis.

In this paper the radon concentration of a big building is presented which was measured over a period of two years with the help of passive and active radon measuring instruments. In order to gain more information about the air movement and usage of the building, the carbondioxide concentration of the building was measured and analyzed. This helped in the interpretation of the course of the radon concentration in buildings. With this knowledge a measurement protocol for the measurement of radon concentration in large buildings could be created.

The obtained data are merged and analyzed for variances and dependencies. In addition, it is examined, how much the measurements can be shortened without losing any relevant information about its reliability.

Beyond one typical building, further buildings will be investigated and studies of other research institutions including this topic will also be looked on to obtain a wide possible range of buildings.

A23

RADON ASSESSMENT OF THE MOST COMMON BUILDING MATERIALS USED IN CHIMBORAZO, ECUADOR

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The capital of the province of Chimborazo is Riobamba city, which was the first city founded in Ecuador in 1534, at Liribamba valley (nowadays Santiago de Quito). Due to an earthquake the city had to move in 1797 to Tapi valley (~20 km far from the original city). The province of Chimborazo presents various types of dwellings, in particular a wide range of building materials, that includes ancient materials preserved from the cities foundation, modern local materials and imported materials specially from Brazil and Italy.

Some studies demonstrate in the Ecuadorian highland region exists building materials can be considering a radon source, for example, materials based on clay and volcanic sediments [1,2].

The present work will show the radon exhalation rate measurements of different building materials used in Chimborazo province. The assessment has been performed with the well-known closed chamber method. The 125 l chamber, built in the Nuclear Techniques Laboratory of the Faculty of science of the Escuela Superior Politécnica de Chimborazo, was interfaced with a solid state detector (RAD7). In addition, this study will present the main parameters used to carried out a correct evaluation using the closed chamber method, the chamber background, the laboratory background, the leakage rate and back diffusion rate. Two methods to determinate leakage rate will be present.

The values of the radon exhalation rate found presents a large variation. The maximum value found is for concrete, and the minimum is for red bricks. The mean indoor radon concentration contribution owing to the evaluated building materials is 5.8 Bq/m^3.

Ref.

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[2] Chávez Oleas, E. M. (2016). Caracterización de radionucleidos presentes en materiales de construcción de minas y canteras de la provincia de Chimborazo y estimación de los niveles de riesgo asociados para la población (Bachelor's thesis, Escuela Superior Politécnica de Chimborazo).

A24

MEASUREMENTS OF RADON AND THEIR PROGENY CONCENTRATIONS IN SHOW CAVES IN SLOVENIA

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There are several thousand caves in Slovenia, some of them are daily occupied by cavers or other visitors and we need to take a care for their effective dose. Radon concentration in caves in summer period can reach 30 kBq/m^3. Because of low air exchange rate also radon progeny concentration can be very high, equilibrium factor goes over 80 %, unattached fraction, f_p, can reach values over 35 %.

Radon concentrations and radon progeny concentrations in two most important show caves in Slovenia, Skocjan caves and Postojna cave, are presented. Radon/progeny concentrations are different if measurements are performed at the same time on different locations in the cave or if thay are performed in different periods of the year. There are some locations in caves where we can get in summer time equilibrium factor between 0.1 or 0.2, but on other location 0.5 or higher value. In winter we measure usually higher values. Mean value of equilibrium factor on one location in Postojna cave in summer time is 0.2, on onother location it is 0.5, in winter thay are much closer 0.6 and 0.8. We have completly another situation in Škocjan caves. Equilibirum factor is much higher through all year, between 0.6 and 0.8.

Measurements of unattached fraction shows big difference between both caves. Average value for Skocjan caves is 0.10 (0.05 – 0.19), in winter period 0.07 and in summer time 0.13. In Postojna cave unattached fraction is much higher than in Škocjan caves, average value is 0.21 (0.04 – 0.38), in winter period 0.12 and in summer time 0.34. Difference between summer and winter period in Postojna cave is more evident than in Škocjan caves. The reason for such difference is in climatic parameters as number of aerosols and ventilation.

A typical tourist tour throuhg the cave takes between one and two hours, depends on the cave, but visitors are walking around 1.5 km. Radon concentrations and aerosol characteristics are different on different locations in the cave. In Postojna cave visitors are walking 1.5 hours and about 30 minutes in a part with higher unattached fraction and lower equilibrium factor. In Skocjan caves visitors are walking about 20 minutes in a part with higher unattached fraction, around 20 %, which is three times lover than in Postojna cave, around 7 %.

All parameters mentioned above are important for dose assessment for tourist guides. Regarding measurements we maybe could use different dose factors for guides in Skocjan caves as it is predicted in ICRP 137.

A25

RADON SOIL-GAS MEASUREMENT CAMPAIGN IN HESSEN - AN APPROACH TO IDENTIFYING AREAS WITH ENHANCED GEOGENIC RADON

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The new radiation protection law (Gesetz zum Schutz vor der schädlichen Wirkung ionisierender Strahlung-StrLSchG) [1] in Germany which came into effect 2018 puts greater emphasis on the protection against naturally occurring radiation, especially radon as known health hazard. The law requires the delineation of radon priority areas, where prevention and remediation of high indoor radon concentrations should be taken with priority. The law required that these areas shall be proclaimed within two years after the law has come into effect. In Germany the radiation protection is the administrative responsibility of the federal states. The state of Hesse has early on decided to fully survey the state for radon priority areas. To identify radon priority areas, the geo-genic radon potential has to be determined [2]. In order to achieve that radon soil-gas measurements combined with soil permeability are a necessity.
The University of Applied Sciences (THM) in Giessen is responsible for the radon soil-gas measurement campaign in Hessen. To achieve a statically sound survey of the state of Hessen with an achievable amount of different measurement locations, and in the given time-frame, a geology-based concept has been designed.
Taking into account the known geological information about geological structures in combination with the administrative counties a survey strategy has been established. Prior known information regarding soil thickness, moisture, dig-ability, and other technical limitations are used to determine the exact measuring locations.

At every location the radon activity in soil- gas is measured in a depth of 1m. The soil permeability is determined for every measurement as well. Three measurements are performed at each location.

Having completed the first set of measurements the design criteria of the campaign as well as the practical experiences will be presented. First results and an update on the radon potential map of Hesse will be shown.

Ref.

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[2] Hoffmann, Bernd. "Die Prognose des geogenen Radonpotentials in Deutschland und die Ableitung eines Schwellenwertes zur Ausweisung von Radonvorsorgegebieten."

A26

RADIONUCLIDE CONTAMINATION IN FOOD AND ESTIMATION OF RADIATION DOSES FROM FOOD INTAKE SINCE THE FUKUSHIMA NUCLEAR POWER STATION ACCIDENT

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A nuclear accident of the Fukushima Daiichi Nuclear Power Station (FDNPS) had been caused by the tsunami after the Great East Japan Earthquake in March 2011, and the huge amounts of radionuclides was dispersed around Fukushima immediately [1]. It is important that the activity concentrations of radionuclide have been continuously monitored in the territorial and marine environment due to understand the dispersion and behavior of radionuclide after the FDNPS accident. Furthermore, the effects of released radionuclides on agricultural, forest and fishery products after the FDNPS accidents have been discussed with the temporal and spatial variations of activity concentrations of radionuclide in the environment.

After this accident, Nuclear Emergency Response Headquarters in Japan started the use of the provisional regulation value in food promptly (March 17, 2011-March, 2012). This concept of the limit for food and water is less than 5mSv/yr. However, it was necessary to carefully consider external and internal exposure due to the FDNPS is located in neighborhood. Based on the concept of 1mSv/yr for food and drinking water, new standard value in food (the limit of general food: 100 Bq-Cs/kg) was enforced from April1, 2012. The concentrations of radiocaesium (R-Cs) in seawater are almost same levels before the accidents except the near site of FDNPS, and these in fish generally decreased, and radiation doses from foods intake are negligible [2]. However, high concentrations of R-Cs are kept to some specific products as food as the result of nutrient cycle, accumulation, translocation and food chain.

In this presentation, we would like to talk about the estimation of internal dose from food intake and the survey of consumer awareness for food in Japan with the monitoring of R-Cs in the environment after the FDNPS.

Ref.

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A27

A COMPARATIVE STUDY OF NATURALLY OCCURRING RADIONUCLIDES AND URANIUM ACTIVITY RATIO IN SOILS OF HIGH BACKGROUND RADIATION AREA OF INDIA WITH FUKUSHIMA SOILS

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Naturally occurring radionuclides such as ^{238}U, ^{232}Th and ^{40}K, are ubiquitous in the Earth's crust and are incorporated in radiogenic minerals such as monazites, ilmenite, rutile, sillimanite and zircon. The areas with radiogenic minerals deposition are responsible for the enhanced natural background radioactivity and widely known as high background radiation areas (HBRA). In India, monazite is abundantly present in placer deposits along the coast of Kerala (southwestern), Odisha (eastern coast) and Tamilnadu (Southeastern). Radiological investigations have been carried out in coastal HBRAs of Odisha and Tamilnadu and extra terrestrial gamma dose rate varied from 0.1 to 1.6 µSv h^{-1}. Natural radionuclide contents in selected surface soil samples were determined using HPGe (High purity germanium) detector and inductively coupled plasma mass spectrometry. The radiation hazard parameters were evaluated from activity concentration of ^{238}U, ^{232}Th and ^{40}K [1]. Uranium concentration and activity ratios were compared between HBRA soils with Fukushima contaminated soils due to ^{137}Cs where dose rate varied from 0.5 to 85 µSv h^{-1}. Uranium isotopes ratios were measured using thermal ionisation mass spectrometry [2].

Ref.

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A28

DEVELOPMENT OF RADIOACTIVE AEROSOL CHAMBER AT HIROSAKI UNIVERSITY, JAPAN

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It is well known that a large part of inhalation dose of radon, which is a risk factor to lung cancer, is due to its progeny. Currently, International Commission on Radiological Protection (ICRP) recommended a new dose conversion factor for radon according to the latest epidemiological studies and dosimetric modelling. However, there are few cases where inhaled aerosols were deposited in the respiratory tract was experimentally investigated. Therefore, it is much important to study how aerosols behave in the respiratory tract. On the other hand, there are also few radioactive aerosol chambers which enable such experiments in the world. In our previous study, a radon/thoron chamber was developed at Hirosaki University [1]. The present study demonstrates the radioactive aerosol chamber developed by applying the radon/thoron chamber, and its performance was evaluated.

The radioactive aerosol chamber is composed of a radon/thoron source, an aerosol generator, a mixing chamber, a bubbling system and an exposure chamber. Aerosols are generated into the mixing chamber by two types of aerosol generators and mixed with radon progeny by the radon source. Radioactive aerosols are provided into the exposure chamber. In this exposure system, the particle size is controlled by changing the concentration of the solution used for an aerosol generation. The humidity is also controlled by the bubbling system connected to the mixing chamber. In order to evaluate performance of controlling the aerosol particle size, the particle size distribution was measured using a Scanning Mobility Particle Sizer (SMPS) and a Laser Aerosol Spectrometer (LAS). The effect of hygroscopic growth was also evaluated. In addition, the activity-weighted size distribution was measured using a cascade impactor and was compared with the size distribution obtained by a SMPS and a LAS.

The geometric mean diameter and the geometric standard deviation were 111 ± 4 nm and 1.7 using the NaCl solution of 30000 ppm in the relative humidity of 21%. In this presentation, more detailed results will be reported.

Ref.

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A29

RADON VARIABILITY DUE TO FLOOR LEVEL IN THE TWO TYPICAL RESIDENTIAL BUILDINGS IN SERBIA

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It is well known that one of the factors that influences the indoor radon variability is the floor level of the buildings. Considering the fact that the main source of indoor radon is radon in soil gas, it is expected that the radon concentration decreases at higher floors. Thus, at higher floors the dominant source of radon is originating from building materials and in some cases there may be deviations from the generally established regularity. On the other hand, the radon variability due to floor level, especially in big cities with a much higher number of high-rise buildings and population density compared with rural environments, may have an impact on the assessments of collective dose from radon.

According to the national typology [1], there are six types of residential buildings in Serbia; two for family housing: Freestanding single-family house and single-family house in a row, and four for multi-family housing: Freestanding residential building, residential building - lamela (apartment block with repeated multiple – lamellar – cores and separate entrances), residential building in a row and high-rise residential building. Distribution of buildings by type at national level shows that 97.23% of all residential buildings are family housing. Also, for all defined types of buildings number of floors ranges from one to eight above the ground level. Freestanding family houses are mostly ground floor (37%) or ground floor with loft in use (26%), while there is a very low representation of houses that have more than two floors (5%), with average height of family buildings of 1.4. In that sense, we chose one freestanding single-family house with loft with well-known radon characteristics [2] and one sixteenth floor high-rise residential building for this study.

The indoor radon measurements are performed with two active devices. One was fixed in the living room at the ground level and the second one was moved through the floors of the residential building. Every measuring cycle at the specified floor lasted seven days with the sampling time of the two hours. In this work, the analysis of the obtained results is shown in details.

Ref.

[1] Jovanović Popović M., Ignjatović D., Radivojević A., Rajčić A., Ćuković Ignjatović N., Đukanović Lj. & Nedić M. (2013), National Typology of Residential Buildings in Serbia, Faculty of Architecture University of Belgrade, Belgrade (2013), ISBN 978-86-7924-102-3.

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A30

RADON EXHALATION FROM BULK AND CRUSHED SAMPLES: FIRST RESULTS ABOUT A STUDY ON SELF-HEALING OF CONCRETE

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In the framework of a project, developed within the context of the COST Action CA15202, about the feasibility of testing the self-healing efficiency by measuring radon exhalation in the vicinity of the crack, several measurments of radon exhalation rate were performed. In this research project, the idea is to use radon exhalation measurements as an indicator of microstructural transformations during the setting and hardening of cementitious materials. Here, first result regarding radon exhalation rate measurements on bulk and crushed sample were presented.

Radon exhalation rate measurements were conducted in a so called climate room (at a constant temperature of 20^{o}C) by radon accumulation in a sealed box for a couple of days (traditional method), using radon monitors type "Radon Eye Plus", equipped with a ionization chamber (figure 1). Moreover the content natural radionuclides of the crushed samples (both fine and coarse fraction were tested) was evaluated using scintillation gamma-ray spectrometer with 2.5x2.5'' NaI(Tl) crystal, protected by the 50-mm lead shielding The samples were put in a tray in order to release free radon gas (these conditions represent deemanated state) before each measurements. After that, the measuring containers (Marinelli's beacker) with these samples were hermetically sealed in order to determine the radon exhalation (after secular equilibrium between radon and its progeny were achieved) and compare with the data achieved with the previous method.

Figure 1. Experimental set up for radon exhalation rate mesurements

A31

THE ROLE OF RADON IN THE PREVENTIVE CONSERVATION OF ROCK ART. THE CASE OF ALTAMIRA

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The presence of high levels of radon gas inside caves is well known. Depending on the morphology of each cave and fundamentally on its degree of connection with the outdoor atmosphere, the concentration of radon can undergo cyclical variations at different time scales.

The case of the Altamira cave is particular and relevant because of different reasons. On the one hand, the cave contains an impressive set of pictorial representations that are mainly concentrated in the so-called Polychrome Chamber. Those paintings are rank among the best artistic manifestations in the history of Humanity, having a value being not only symbolic, but also technical and representative. Because of this, Altamira Cave was declared World Heritage Site in 1985 by UNESCO. On the other hand, the cave has a shallow karstic structure that confers a degree of communication with the exterior unusual in other caves. This fact favors not only the existence of seasonal variations in the indoor radon concentration, but also the observation of fluctuations of much shorter period (weekly or daily) which are related to rapid exchanges of air in the Polychrome room.

These particularities make the continuous monitoring of radon concentration a relevant tool within the rock art conservation plan. This work will present an overview of the role of radon gas within the framework of preventive conservation strategies of heritage. Its involvement in recent episodes where variations in its concentration have turned out to be a good indicator of other variables related to the preservation such as air temperature, specific humidity or CO2 concentration.

Refs.

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A32

INTERPRETATION OF THE CHARACTERISTICS OF A LONG RADON TIME SERIES AT CAMPI FLEGREI CALDERA (ITALY)

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A large study on long-term monitoring of Radon time series data (seven years) at two sites in the Campi Flegrei volcanic area (Naples, Italy) is presented. Measurements were performed with the RaMonA system which is based on measurement of the alpha particles of the daughters of Radon and Toron[1]. The time series are drawn with powerful mathematical methods[2,3] (hybrid methods) to capture and interpret radon trends and anomalies due to volcanic-seismic events. The investigations on the gas composition of the monitoring area were carried out in relation to the characteristics of the time series studied. A particular novelty is that the Radon signal was studied in connection with the fumarolic tremors recorded in a site of the Campi Flegrei area. Their trends and the results of |the obtained forecasts confirm recent studies that have shown a new and long unrest phase in that area. This phase has greatly influenced public opinion in Italy in recent years.

This work provides potentially very powerful tool for capturing and interpreting earth movements and seismic events, including those located in many geographically remote areas. Using these procedures, it is possible to re-evaluate the Radon signal to obtain information that other geophysical and geochemical parameters do not provide or to confirm the information provided by other parameters.

Ref.

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A33

RADON AND CO_2 MONITORING IN THE VAŽECKÁ CAVE, SLOVAKIA

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The Važecká Cave (Northern Slovakia) is developed in the Middle Triassic dark-grey Limestones of the Gutenstein Formation of the Hronic Unit at the contact of the Liptovská Basin and Kozie chrbty Mountains, by ancient ponor waters of the Biely Váh side branch (Havrila, 2011).

The continual monitoring of ^{222}Rn activity concentration and CO_2 started in 2012 and is still being carried out. Three monitoring stations were established in the cave: Gallery (operates from May 2012), Lake Hall (operates from November 2015) and Entrance Hall (operated from November 2015 to October 2017). Besides radon and CO_2 concentration, internal air temperature and relative humidity are continually measured at each station. Radon is registered using Barasol detector (Algade). The cave is also equipped with the external meteorological station. Data are collected with a sampling period of 10-minutes.

Radon activity concentration and CO_2 concentration in the Važecká Cave atmosphere exhibited annual, non-periodic short-term and periodic daily variations. Radon reached its maximum in summer months, from June to September. Annual maximum of CO_2 concentration is registered approximately one month later than radon maximum.

Multi day radon variations lasting up to 15 days were observed at all three stations. Most of them were registered simultaneously at the Lake Hall and the Gallery station and they coincided with CO_2 multi day variations.

Daily variations were observed at all three station, but the position of daily maximum and minimum was not identical. During a whole year radon maximum in the Gallery corresponds to radon minimum in the Lake Hall and the Entrance Hall. The highest daily radon amplitude in all stations is observed from May to September.

The spatial differences in radon activities among stations were confirmed. The highest radon and CO_2 levels were found in the Gallery, the most distant station from the cave entrance, where daily average of radon concentration radon reached up to 50 kBq/m^3 and CO_2 concentration up to 7600 ppm.

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A34

PILOT STUDY ON MITIGATION SOLUTIONS FOR BUILDINGS WITH AN ELEVATED RADON LEVELS IN SERBIA

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Radon contributes to almost 50% of the overall high-effective annual dose to the population received from all sources of natural radioactivity. Harmful effects of radon have been proven in a large number of epidemiological studies. Radon problem has received a special attention in many countries in the world and most of them have established national radon programmes.

Serbian Radiation and Nuclear Safety and Security Directorate (SRBATOM) conducted National Indoor Radon measurement campaign in more than 5 thousands dwellings in the Republic of Serbia. We used CR-39-type detectors, period of exposure was six months, in heating season. The results showed that 3% of all measurements are above the intervention levels for chronic exposure to radon in homes 400 Bq/m^3 for existing buildings and 0.3% of all results were above 1000 Bq/m^3.

In 2017 SRBATOM established multi-disciplinarian team consisting of experts for indoor radon measurement and building professionals. We chose 20 houses with an elevated radon levels (at voluntary base) and devised the project on two parts: one was consisted of indoor radon diagnostics with active device and the second one was technical analysis of houses which included existing conditions of the house, used technical standards during the building process and building codes. In this work we represent obtained results in details, with outcomes on mitigation solutions for the investigated houses.

A35

EVALUATING MTBE RESIDUAL CONTAMINATION IN GROUNDWATER USING RADON

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About 15 years ago, a fueling station in Roma (Italy) was dismissed. When underground tanks were removed, a subsoil NAPL (Non-Aqueous Phase Liquid) contamination came out, showing gasoline leakage from the reservoirs bottom. Monitoring actions took place next and only recently radon dissolved in groundwater was measured and used as tracer of NAPLs in view of its high solubility in these substances. The relative deficit of radon in polluted groundwater compared to radon levels in background "clean" water allows to detect areas where residual gasoline is located. After 15 years of degradation and volatilization, only residual lenses of MTBE (a resistant additive introduced in place of lead) are still present. When groundwater table rises, removal of MTBE takes place, increasing its concentration in groundwater. This value is then progressively reduced because of natural attenuation processes.

Radon-deficit in groundwater from 12 monitoring piezometers was determined for a period of seven months, from September 2018 to March 2019. The source of pollution, where former underground gasoline tanks were placed, is clearly evidenced by local low radon activity concentration. This finding is strengthen by direct measurements of higher contents of dissolved NAPLs. A short plume of contamination, elongated in the direction of groundwater flow, has also been recognized, using both radon-deficit and direct chemical analyses.

Temporal variation of MTBE concentration, inferred from direct measurements, is not evident from radon data in the area where the source is located, but it seems that piezometers placed downgradient record this change.

Quantifying dissolved MTBE from radon-deficit equations is difficult and problematic when gasoline spillage is not recent, since only residual and strongly degraded NAPLs occur, leading to a strong overestimation. On the contrary, when a rise of groundwater table removes the pollutant, increasing its dissolved contents, the above mentioned quantification model seems to work much better. The half-life of natural attenuation, linked to periodical rises of groundwater level, was estimated at about 23 days.

Additional information could be provided by in situ measurements of soil gases (radon, carbon dioxide and methane) in order to find residual pockets of NAPLs in the vadose zone. Studies on the natural bio-degradation of gasoline could be of further interest.

A36

RADON MEASUREMENTS IN GROUNDWATER USED TO SUPPLY THE URBAN AREA OF RIOBAMBA CITY

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Riobamba is located at 1°41'46 " south, 0°3'36" western of Quito meridian at 2754 m.a.s.l. The mean annual temperature fluctuates from 13 to 25 C. The City has an approximate area of 30 km^2. The 69.43% of the inhabitants are located in the urban area. The area where the city sits is formed by 12 geological units, which include volcanoclastic sediments, basaltic, pyroclastic, int rusive, stuff and andesitic stones, shales and grauvacas [1].

The water consumed by Riobamba comes from 37 artificial wells (groundwater extraction) and 27 natural water springs. There are two main places where water sources are found: Llio and Alao-Maguazo (according to Ministerial Agreement 134, published in the Official Registry Supplement No. 812 of October 18, 2012) [2]. The present study reports the radon activity concentration in water samples coming from Llio wells and the spring waters located at the Alao-Maguazo area.

Three samples were taken for each source, at least three times during half a year, and data such as water and air temperature, water flow rate, and gamma background radiation will be reported. The technique used for the analysis is passive diffusion using ionization chambers type E-PERM.

The maximum radon activity concentration found is (221.7 ± 1.6) Bq/l and the minimum is (2.0 ± 0.6) Bq /l. The geometric mean value is (8.3 ± 0.8) Bq/l. The 99% of the sources measured are within the maximum permissible concentration limit of 222Rn in drinking water according to the EPA and EURATOM. The average dose due to the inhalation of radon from water is (0.059 ± 0.006) mSv/year, for a person who is exposed during 200 hours in a year. The average dose due to the ingestion of water coming from the studied sources is (0.010 ± 0.001) mSv per year.

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A37

RADON LEVELS AND ASSOCIATED DOSES IN INDOOR ENVIRONMENT OF GARHWAL HIMALAYA

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The annual exposure to indoor radon, thoron and their progeny imparts a major contribution to inhalation doses received by the public. In this study, we report the time integrated passive measurements of indoor radon, thoron and their attached and unattached progeny concentrations that were carried out in Garhwal Himalaya with the aim of investigating whether the exposure to these nuclei involves significant health risk to the dwellers of the investigated region.

The measurements were performed using recently developed LR-115 detector based Pin-hole dosimeter, DRPS/DTPS in bare mode and wire mesh capped DRPS/DTPS techniques. The experimentally determined values of radon, thoron and their progeny concentrations were used to estimate the total annual inhalation dose and annual effective doses. The equilibrium factors for radon and its progeny and for thoron and its progeny were also determined from the observed data. The estimated value of total annual inhalation dose was found to be 1.8 ± 0.7 mSv/y. The estimated values of annual effective doses from the exposure to radon and its progeny and from the exposure to thoron and its progeny were found to be 1.2 ± 0.5 mSv/y and 0.5 ± 0.3 mSv/y, respectively. The estimated values of radiation doses have shown no significant health risk due to exposure of radon, thoron and progeny in the study area. The contribution of indoor thoron and its progeny to the total inhalation dose ranges between 13% - 52% with the mean value of 30%.

Thus thoron cannot be neglected when assessing radiation doses.

A38

GEOCHEMICAL STUDY AND EVALUATION OF PREDICTIVE MODELS FOR SOIL GAS RADON CONCENTRATION IN A GRANITIC AREA IN HUNGARY

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Since radon is the most import source of natural terrestrial radioactivity that we are exposed to, it is important to evaluate role of physical and geochemical properties of the soil that determines the potential of radon as a risk for human health. The goals of this study are: 1) to determine the chemical and mineralogical composition of the soil, as well as the spatial distribution of U-238, Th-232 and Ra-226, and 2) to test the usability of predictive models, using chemical and and physical properties as independent input parameters, to determine the soil gas radon concentration by comparison with field measurements.

This study was performed in the western side of Velence Hills in Hungary, near Pákozd settlement, in a 0.8 km^2 downhill meadow area that belongs to re-deposited slope debris on the Velence granite formation. Field measurements and soil sampling were carried out in three replicates at 30 randomly selected sites. The chemical and mineralogical composition of the soil samples were determined to evaluate the spatial distribution of the geogenic sources of radon in the area. In situ measurements of soil gas radon activity concentration were compared with the correspondent values obtained by applying theoretical models. These models use the laboratory measured radium/uranium ratio, radon emanation coefficient and soil physical properties, for instance, dry bulk density, porosity and water content of soil samples. Effects of additional geochemical properties such as clay mineral, organic matter and carbonate content were also studied. The values of soil gas radon concentration obtained from the predictive models are numerically different, however they are significantly correlated (r=0.6, p=0,001). These differences correspond to the contribution of the underlying rock that are not considered in the predictive models. Therefore, rock properties were included into the models (Ra-226 content, emanation).

Consequently, the differences in the measured and predicted values are significantly reduced, thus the predictive power of the modified model for soil gas radon concentration increases. Soil gas radon decreases with the increasing amount of sand and increases with the decreasing amount of silt and clay due to the radioactive element bearing heavy minerals occur below the sand grain fractions.

A39

^{222}Rn AND ^{220}Rn LEVELS IN BAYAN OBO RARE EARTH MINE

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Bayan Obo Rare Earth Mine in Inner Mongolia is the world's largest open pit rare earth mine. In order to understand the exposure level of radon and thoron in the living areas and workplace near the mine, investigations were conducted on the concentration levels of radon and thoron in the soil gas and indoor and outdoor air in the mine living area and tailings dam.

In the survey, AlphaGAURD PQ2000Pro was used to measure radon concentration, and radon monitors of RAD-7 and ERS-RDM-2S were used to measure radon and thoron concentrations.

The survey results obtained the following conclusions:

1. There is a significant difference in radon concentration in soil gas at different sites, depending on the soil radium content and soil physical properties. The concentrations of ^{222}Rn and ^{220}Rn at the 80 cm depth of the soil at an anomaly zone in the mine living area were 67.5±4.52 kBqm^{-3} and 79.2±6.81 kBqm^{-3}, respectively. The repeated measurements were 61.14±4.18 kBqm^{-3} and 53.3±5.59 kBqm^{-3}; and the mean of the concentrations of ^{222}Rn and ^{220}Rn in the background area were 3.90±1.19 kBqm^{-3} and 35.05±4.37kBqm^{-3}, respectively.

2. It is found that there is a building with high ^{220}Rn concentration in the area of Bayan Obo, and it varied drastically. The indoor average ^{222}Rn concentration is 71.32±22.84 kBqm^{-3}, ranging from 45.85 kBqm^{-3} to 99.12 kBqm^{-3}; the indoor average value of ^{220}Rn concentration is 15.03±8.36 kBqm^{-3}, and the variation range is from 8.36 kBqm^{-3} to 20.54 kBqm^{-3}. The indoor average radon concentration measured by the PQ2000 and the radon progeny instrument (ERS-RDM-2S) is completely consistent with the RAD-7 measurement result. The measured average value of the equilibrium equivalent concentration (EEC) of thoron is 0.35±0.11, and the indoor ^{220}Rn concentration is less than 17 Bqm^{-3}. The indoor ^{220}Rn concentration in the working field near the tailings dam is obviously high, and the maximum value is 215.59±262.86 Bqm^{-3}.

3. The concentration of ^{222}Rn and ^{220}Rn in the outdoor air shows a certain regularity. As the height of the measurement increases, the concentration decreases; the EEC of thoron is very low, and the variation law is not obvious.

Since the half-life of ^{220}Rn is very short and the half-life of its daughter is very long, the ^{220}Rn measurement is very difficult. Our measurement results are useful for studying the measurement method of ^{220}Rn in the air and evaluating the irradiation dose due to ^{220}Rn and its daughters to the public.

This project is co-funded by the National Natural Science Foundation of China (No. 41674111) and Ministry of Science and Technology of the People's Republic of China (the 37th China-Poland Science and Technology Conference Exchange Program 37-10).

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A40

PRELIMINARY SURVEY OF ^{222}RN CONCENTRATION IN DWELLINGS & DRINKING WATER AT HIGH BACKGROUND RADIATION AREA BOTTENG, MAMUJU, INDONESIA

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Mamuju is one of the areas in Indonesia that has high exposure to natural radiation. Based on the results of a study conducted by the Radiation and Metrology Safety Center-BATAN (PTKMR-BATAN) which states that the gamma radiation dose level in Mamuju area reaches 2,800 nSvh^{-1} with average radiation dose rate is 631 nSvh^{-1} and this value is above the average natural radiation dose rate in Indonesia, which is 50 nSvh^{-1}. Radon and its progeny in the indoor environment have been identified as the primary sources of radiation dose to the people from natural radioactive sources. Presence of radon in dwellings and drinking water causes radiation-related health hazards both through inhalation and ingestion.

This study aims to determine the radon levels in the dwellings and drinking water also estimate the effective annual dose and internal doses. In this study, 20 houses were installed the Raduet® monitor as Solid State Nuclear Track Detectors (SSNTDs) made from CR-39 for two months exposures time and also measure the daily indoor radon concentration using RAD7 for three days continuous measurement and then for the drinking water, 14 samples were measured by RAD7.

The results of indoor radon are 60 - 880 Bqm^{-3} with daily radon concentration the highest on midnight. For drinking water, the concentration result obtained 3-570 Bql^{-1}. The annual effective doses obtain 0.8-22.2 mSvy^{-1} and the ingestion dose result from 6,0 $\times 10^{-4}$ - 0.12 mSvy^{-1}.

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A41

POTENTIAL RISKS OF RADON IN SOILS TO THE INDIGENOUS MICROORGANISM:
A CASE STUDY OF GANGHWA ISLAND IN SOUTH KOREA

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Radon is the most common natural radioactive nuclide, damaging the crucial cellular components such as nucleic acids, proteins and lipids [1]. It can simultaneously induce the oxidative stress, so-called reactive oxygen species generated from the water radiolysis over live organisms neighbored [2]. Nonethless, some microorganism can resist against the ionizing radiation by adapting them as of keeping the genetic redundancy or expressing the proteins capable of protecting to cure an impaired DNA [3]. However, there is still a lack of knowledge for the environmental risk of radon and other radioactive materials. Hence, this study was investigated on the metabolic activity of *Bacillus velenzensis* under the radon exposure, and soil bacterial isolates have been collected from Gang-Hwa island, Korea.

B. velezensis exposed to a degree of different radon levels in the tightly sealed chamber equipped with radon reservoir at the various experimental conditions where their radon concentrations were varied from 200, 500, 800, 1,500 to 3,000 Bq/m^3, each of which was temporally exposed for 1, 3, 5, 7, and 9 h. Thereafter, they were all commonly incubated in the fresh LB broth medium (containing Tryptone 10g/L; Yeast extract 5 g/L; and NaCl 10 g/L) to estimate the variation of the microbial population density (as of optical density at 600 nm), colony forming (CFU/mL), and dehydrogenase activity. Indigenous soil samples were analyzed with the same manner, and radon in soils was measured using FRD 400 (Radon FT Lab, Korea).

As a result, dehydrogenase activity of *B. velezensis* was diminished when radiation intensity has been exceeded beyond the certain level; for example, at the 6th h of incubation, its microbial density was decreased to 22.4% (exposed to 200 Bq/m^3), 67.6% (500 Bq/m^3), 45.0% (800 Bq/m^3), 42.7% (1,500 Bq/m^3) and 41.8% (3,000 Bq/m^3) compared to the control, respectively. Although this bacterial strain restored their own growth rate along with enzymatic activity as the incubation was prolonged, the extent of metabolic activity has been dwindled. It delineates that radon can be considered to be acted as for a potential environmental risk against the ecosystem. In the field survey, we have found such a consistency previously observed from the microbial exposure tests by the fact that the heterogenous microbial culture isolated from soil samples also have a higher metabolic activity in the medium level of radiation (*i.e.*, 500 – 1,500 Bq/m^3) than other ranges of radon radiation either lower or higher.

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A42

TECHNOLOGY FOR REMOVAL OF RADON AND RADON DAUGHTERS FROM DRINKING WATER

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Underground water is one of the main sources of radon for households. This paper focuses on the estimation and removal of radon from underground water using systems and inorganic sorbents developed by EKSORB for the treatment of liquid radioactive waste in the nuclear industry.

The paper discusses testing of a system for the removal of radon and radon daughters from water patented by EKSORB. This is achieved by filtering through RATZIR sorbent, followed by periodic load regeneration with hot water and washing down to a settling tank where radon and radon daughters decay. Over a period of 3 years, the plant removes radon from water with the initial radon content of approximately 1,500 Bq/L to less than 60 Bq/L, without releasing radon to indoor / outdoor air.

A number of methods based on direct gamma-ray spectrometry, emanometry, and liquid scintillation counting are usually used to measure radon activity levels in water [1]. These methods offer quite low detection limits ranging from 0.05 to 10 Bq/L but require expensive equipment and may be applied only in specially equipped laboratories. The article also describes testing of the Sorben-Tec system patented by EKSORB for rapid evaluation of radon in natural water using a domestic personal dosimeter or survey beta radiometer [2]. The system consists of a plastic lid for a 5-liter bottle and a small sorption column with inorganic sorbent. The tests were carried out on natural water samples with radon content up to 1,500 Bq/L. It is shown that the limits of radon detection in water for a 5-liter sample are 35 to 40 Bq/L when the dosimeter is used and 10 Bq/L when the beta radiometer is used, which is more than adequate for quick detection of water with radon concentration higher than standard limits. The analysis takes about 1 hour, excluding the waiting time for radon daughters to accumulate in water (3 to 5 hours).

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POSTER PRESENTATIONS

P01

IMPLEMENTING OPTIMIZATION IN PROTECTION FROM RADON EXPOSURE IN WORKPLACES AND DWELLINGS: SOME PROPOSALS

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As a consequence of results of many epidemiological studies on lung cancer risk and radon exposure in dwellings and mines, the most recent European directive on basic safety standards for protection against the dangers arising from exposure to ionizing radiation – i.e. the *Council Directive 2013/59/Euratom* – have introduced requirements for protection from radon exposure in dwellings and have strengthen the requirements for protection from radon exposure in workplaces.

Similar protection requirements have been introduced in the *International Basic Safety Standards on Radiation Protection and Safety of Radiation Sources*, jointly sponsored by several international organizations and agencies (EC, FAO, IAEA, ILO, OECD/NEA, PAHO, UNEP, WHO).

A basic principle of radiation protection, adopted also by the two mentioned international regulations, is the optimization principle. However, implementation of optimization for radon exposures in dwellings and workplaces poses several challenges. An important example is the replacement of the concept of *action level* for indoor radon with the much more ambitious optimization tool of *reference level*, which requires that optimization is applied with priority for radon concentration levels greater than the reference level, but optimization has to be applied also for radon levels below the reference level [1].

In this presentation, some proposals on how to apply the optimization principle for protection from radon exposure in dwellings and workplaces in the framework of the two mentioned international regulations will be presented and discussed, taking into account that the final goal is to reduce the individual and collective risk of lung cancer, i.e. the number of lung cancers attributable to radon.

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P02

RADON IN THE WORKPLACE - REGULATORY FRAMEWORK AND EXPERIENCES IN CZECH REPUBLIC

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In the Czech Republic, radiation protection in the workplace with natural sources of ionizing radiation 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.

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P03

RADON MIGRATION EXPERIMENTS

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The main goal of the research presented was to estimate the time and diffusion length for radon in the geological structures of Upper Silesian Coal Basin (USCB) and advection of ^{222}Rn with other gases like carbon dioxide or methane, occurring in the Carboniferous strata in USCB. This knowledge will support the precision of the assessment of radon hazard in dwellings. Moreover, it should give an answer to some questions, related to the radon migration issues – if the results of measurements of an adhesive transport of radon with other gases in the strata could be applied for the prediction of geodynamic phenomena in the mining areas, like tremors and outbursts.

For this purpose a special device was designed and constructed. This device consists of the container for the sample of coal, mineral or rock and two reservoirs – the inlet and outlet one. The gas (air, carbon dioxide, methane) with radon is introduced into inlet reservoir, while the content of marker gases and radon is monitored in the outlet reservoir. The preliminary experiments were also performed and are presented in this paper. In the literature, there are only rare results of such investigations, while our previous research in USCB region showed some correlation between sudden changes of radon level and geodynamic events. Therefore, the results of the investigations presented in this study are expected to contribute to the improvement of the models of these phenomena.

P04

A NEW TOOL FOR THE ANALYSIS OF THE GEOGRAPHICAL VARIABILITY OF THE INDOOR RADON ACTIVITY: RESULTS FROM A CASE STUDY IN CAMPANIA (SOUTHERN ITALY)

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In this work we aim to determine the geographical variability of Radon concentrations at different spatial scales. We tested the method through a case study performed in Campania region (Southern Italy).

To quantitatively assess this geographical variability, some statistical tools were used referred to as Lorenz curves and Gini coefficient. Such tools are widely used for socio-economic applications and have also been used in a previous work to determine seasonal variations in Rn concentrations in UK [1]. The Lorenz Curve is a graphical representation of the inhomogeneity degree of a distribution, while the Gini coefficient is a quantitative estimate of such inhomogeneity. This coefficient ranges from 0 to 1: lower values indicate a pretty uniform distribution, while higher values stem from inhomogeneous distributions.

These two tools were used to study the distributions of the indoor radon concentration measurements that were performed by means of passive radon detectors, equipped with a pair of LR-115 solid-state nuclear track detectors (SSNTD) provided by Dosirad (Pierrelatte, France). For each dwelling, the detectors were exhibited for one year, providing as output two six-month measurements [2].

The Campania region is characterized by a complex tectono-stratigraphic evolution that led to the formation of a great variety of geological environments [3]. They range from the coastal plains with volcanic complexes (e.g. Vesuvio, Campi Flegrei, Procida-Vivara, Ischia) to the inner sectors of Southern Apennines.

As expected, large Gini coefficients emerged from the analyses over regional distances owing to the variability of the main geological features. Nevertheless, large coefficients were sometimes estimated even over smaller spatial scales, highlighting the need of more detailed geological maps to explore and interpret such an inhomogeneity.

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P05

OPTIMIZATION OF THE ETCHING CONDITION FOR THE NEW SCANNER-BASED TRACK DETECTOR EVALUATION SYSTEM

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More than half part of the natural background radiation arises from the radon isotopes and their daughter elements. The harmful health effects of these isotopes are well known for a long time. To reduce these effects the reference level for the maximum indoor radon concentration has been recommended by the international organizations. Above these level radon activity concentration has to be reduced by active methods.

The measurement of the indoor radon is carried out by solid-state nuclear track detectors. At the University of Pannonia an old optical microscope-based system was used for the detectors' evaluation. Recently a new scanner based evaluation system was developed at this Institute. For this the development of etching system was necessary.

After the systematic review of the etching system a new, quality guaranteed etching method was developed. The calibration sheet for the determination of the optimal track diameter range was prepared by ArF excimer laser. It was certified by profilometer technique that the marks on the detector's surface by the ArF laser was acceptable: there was no changes in the detector's material. The optimal track diameter range for the new system is 40-60 μm. New etching conditions for this range was determined: 6.25M NaOH, 90°C and 8 hours. The possibility of the reuse of the etching solution was investigated. It was observed that the etching velocity was not influenced by the concentration of the etching products in the solution, but the reuse of the solution is not recommended because of other disturbing parameters (e.g. absorbed CO2).

P06

COMPARISON OF DIFFERENT TYPE OF TRACK DETECTORS FOR THE SCANNER-BASED EVALUATION SYSTEM

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According to the new EU-BSS, the preparation of the National Radon Action Plan is obligatory for the European countries. One of the plan's aim is to carry out an indoor radon survey to identify the radon-prone areas. In case of indoor radon surveys track detector methods is used because of their simplicity and cheapness.

At the University of Pannonia a new scanner-based track detector evaluation system was developed in the last years, which is suitable to evaluate huge amount of track detectors. This system can be acceptable for the evaluation of CR-39 because this type is transparent.

In this study two different types of CR-39 track detectors (Baryotrak and Tastrak) was investigated from the aspects of background and sensitivity for radon during one year period. The Baryotrak detector's background track density (0 – 1.5 track cm-2) is lower than the Tastrak detectors' track density (0.8 – 4 track cm-2). The difference between the average values is 37 %.

It was determined that the sensitivity for radon of the Tastrak detectors is higher, but the deviation of the calibration factor is much higher (1.2 ×10-3 – 5.3×10-3 track cm-2/Bq day m-3) than in case of the Baryotrak detectors (1.4 ×10-3 – 2.8×10-3 track cm-2/Bq day m-3). No tendency in the fluctuation of the calibration factor was observed, but the background track density is increased: this rate was 15% in case of Baryotrak detectors, and 40% for Tastrak detectors. No tendency between the temperature of the storage and the changes of the background track density or calibration factor was observed. Based on the results the Baryotrak detectors are recommended for the measurement procedure because of the lower background and smaller calibration factor's deviation.

P07

Determination of the thoron emanation coefficient for natural materials.

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Thoron (^{220} Rn) is a naturally occurring radioactive gas, which is carcinogenic just like radon (^{222} Rn) but due to a small amount in the environment and a short half-life (55.6s), its share in the absorbed radiation dose is often neglected [1]. In the case of materials that do not contain a large amount of thorium (^{232}Th), determining the emanation coefficient for the thoron, considering its short half-life, is a demanding undertaking.

To determine thoron emanation coefficient, the method developed by S.D. Kanse [2] was used. It was improved and adapted to the equipment used in Laboratory of Radiometric Expertise IFJ PAN. 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 AlphaGuad DF2000 detector [3]. Due to the medium content of the thorium in the material, the mass of the sample had to be increased from 1 gram to about 25 grams, and at the same time the thickness of the sample could not be greater than the length of the thoron diffusion. The thickness of the sample is very important for avoiding significant loss of the thoron due to intergranular absorption and facilitates the complete removal of this gas escaping from the powder. Therefore, the material is placed between 2 filters and then closed in a special holder made on a 3D printer. 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 (according to the ^{208}Tl isotope) 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.

The emanation factor calculated on the basis of the results obtained from the experiment was S1: 0,002 ± 0,0003:, S2: 0,002 ± 0,0003, S3: 0,002 ± 0,0005, S4: 0,002 ± 0,0006, S5: 0,002 ± 0,0005 , S6: 0,001 ± 0,0002.

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P08

CYTOGENETIC BIOMONITORING OF INHABITANTS OF A LARGE URANIUM MINERALIZATION AREA ON EXAMPLE OF KOWARY, POLAND

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Introduction: Radon-induced biological effects have been studied mainly through epidemiological investigations, and well-controlled in vitro and in vivo experiments. To provide data explaining radon exposure-induced harmful effects in natural environment, environmental exposure assessment is needed. The objective of the study was to examine the level of genetic damage assessed by DNA single- and double-strand breaks (SSBs and DSBs) in peripheral blood mononuclear cells obtained from individuals continuously exposed to Rn concentrations in homes. Naturally elevated radon concentrations in homes can be found in the South of Poland, in Kowary. *Method*: Measurements of expression of phosphorylated histone γ-H2AX was used as a sensitive marker of double strand DNA damage. To detect single-strand, double-stand DNA breaks and alkali labile sites, the alkaline comet assay was used. Oxidative damage of DNA was evaluated by formamidopyrimidyne (FPG)-modified comet assay. The blood was collected from 94 volunteers living in Kowary. Subjects were grouped as living in radon concentration above 100 Bq/m^3 (n = 67), and below 100 Bq/m^3 (n = 27). *Results:* The statistically significant differences in levels of DNA damage in peripheral lymphocytes assessed by comet assay were found to be associated with levels of radon exposure in indoor air (p=0.034). DNA damage in the comet assay was significantly correlated with DNA damage assessed γ-H2AX staining. *Conclusions:* Results of the present study indicate the suitability of alkaline comet assay for the detection of DNA damage in peripheral blood lymphocytes of people environmentally exposed to radon [1].

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P09

DEVELOPMENT OF APPROACH TO ASSESS THE RATIO BETWEEN THE ADVECTIVE AND DIFFUSIVE RADON ENTRY INTO BUILDINGS

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An approach to assess the ratio between the advective and diffusive radon entry was developed. For this purpose were used some results of the radon survey of few children's institutions in the city of Lermontov, Caucasian Mineral Waters region of Russia. This region belongs to the zone of high geogenic radon potential. The measurements were carried out using solid state nuclear track detectors. Radiometers were exposed twice a year for at least two months. Four schools and seven kindergartens were surveyed. Total number of surveyed rooms was 697, including 578 rooms both in cold and warn seasons. We calculated median room area-weighted radon concentration levels by season and floor of buildings. It was obtained that each building can be assigned to one of the following groups: 1) primarily advective radon entry from the soil 2) primarily diffusive radon entry. Group 1 includes buildings with significant elevation of radon concentration during the cold period of year (average outdoor temperature < 5°, heating period) and radon concentration much higher on the ground floor compared to first floor. Group 2 includes buildings with radon concentration weakly dependent on both the season and the floor. Maximum levels of radon concentration are observed in buildings of Group 1: the area-weighted average median is 529 and 256 Bq/m^3 in winter on the first and second floor, respectively, 344 and 138 Bq/m^3 in summer on the first and second floor, respectively. For buildings of Group 2, these values are: in winter - 85 and 104 Bq/m^3, in summer - 94 and 88 Bq/m^3. Thus, radon concentration achieves the maximum during the heating period in buildings with predominance of advective transport in the soil-building system. Using the obtained results, comprehensive in-depth surveys of buildings of all children's institutions of the city are planned to identify sources and pathways of radon entry into buildings.

P10

URBAN CLIMATE STUDIES USING RADON-222 – CENTRAL POLAND CASE STUDY

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Urban regions are responsible for increased amount of anthropogenic emissions (heat, trace gases, particulates) and can impact climate on local and larger scales. The present investigations are an extension of urban climate studies using the natural radioactive gas radon (Rn-222) to (1) improve our understanding of urban canopy processes on diurnal to seasonal timescale (2) verify that it is a valuable tool for detailed quantitative characterization of urban canopy influence on selected unique characteristics of local climate, i.e. air temperature and humidity, components of the surface energy balance and urban mixing depth, as a function of atmospheric stability [1, 2, 3, 4, 5]. A recently-developed radon-based nocturnal stability classification technique [1, 5] was used to characterise the local (25-50 km scale) atmospheric mixing state, and then investigate the climatic influence as a function of the local stability.

Four years (2008-2011) of paired hourly near-surface meteorological and atmospheric radon measurements (AlphaGUARD® PQ2000PRO) from adjacent urban and rural sites were analyzed. The urban station was located in the centre of Lodz (3rd most populated city in Poland, ca 725,000 inhabitants, area 293 km^2). The rural station was located 25 km to the north, in the district of Ciosny, and is representative of typical agricultural land with low vegetation and sparse dwellings.

The radon-based stability classification technique was employed to characterise the Urban Heat Island Intensity, radiation balance, sensible heat flux, latent heat flux, surface energy budget, near-surface temperature gradient, wind speed, and humidity over the full diurnal cycle for five distinct atmospheric mixing states [2, 3]. This radon-based technique is demonstrated to be an effective tool for assessing the efficacy of mitigation measures for urban climate effects in a consistent way over timescales of years to decades.

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P11

ANALYSIS OF RADON TIME SERIES FROM UNDERGROUND ENVIRONMENTS IN PORTUGAL AND SLOVAKIA

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Underground workplaces are characterized by an increased health risk from exposure to natural ionizing radiation. The parameters driving the variations of radon concentration and gamma radiation measured in three underground monitoring stations are investigated within the frame of a bilateral mobility project „Radon in caves and mines - Portuguese and Slovak case studies (RADCAMIN)", between INESC TEC, Porto and Earth Science Institute, Slovak Academy of Sciences. Radon signal was registered using the same sensor (Barasol alpha detector, Algade) at the Domica Cave (Southern Slovakia), the gallery of St. Anthony of Padua (Central Slovakia) and at the former Uranium mine of Urgeiriça (Central Portugal). Time series of radon activity from the three sites are analyzed together with environmental (meteorological and microclimatic) parameters.

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P12

RADON AND THORON EXHALATION RATE MEASUREMENTS OF BUILDING MATERIALS USED IN SERBIA

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Based on the recent epidemiological studies performed in Europe, Asia and America, radon is recognized as the second radon important human carcinogen for lung cancer, after smoking. The main source of indoor radon concentration is soil beneath the dwelling, while the second important source of radon is building material.

In recent years, with an increase of environmental awareness and energy saving policy, residents tend to live in dwellings with more tight doors and windows and new materials with better thermal isolation have been introduced to civil engineering. All these leads to a decrease of air exchange rate and consequently an increase of indoor radon concentration. Such an increase is observed in multi-storey buildings [1], where the major source of indoor radon concentration is building material.

Furthermore, it was shown that under certain conditions, in dwellings with very low air exchange rate, a dose received due to inhalation of radon and its progeny can be higher than a dose received from the external exposure to ^{226}Ra concentration in building material [2].

Therefore, although it is not mandatory to control radon exhalation rate from building materials, abovementioned arguments are underlying the importance of the radon exhalation rate measurements.

In this contribution, the results of radon (^{222}Rn) and thoron (^{220}Tn) exhalation rate for some typical building material used for construction and decoration of houses in Serbia are presented. Exhalation rate measurements were performed using close chamber method, while concentration of radon and thoron in chamber was continuously measured using RTM1688-2 of SARAD® GmbH company. The impact of the replacement of windows on the indoor radon concentration is estimated.

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P13

EFFECT OF ELECTRONIC CIGARETTE (EC) AS AEROSOL SOURCE ON PARTICLE SIZE DISTRIBUTION IN INDOOR AIR AND IN STANDARD RADON CHAMBER

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The Particle Size Distribution (PSD) is the important factor governing if the aerosols can be deposited at various respiratory tract regions in human. Recently, Electronic Cigarette (EC), as the alternative of tobacco cigarette, is increasingly popular all over the world. However, emissions from ECs may contribute to both indoor and outdoor air pollution and comments about the safety remain controversial, the number of users is increasing rapidly. In this investigation, aerosols are generated and studied from ECs in indoor air and in a chamber under controlled conditions of radon concentration. Generated aerosols are characterized in terms of particle number concentrations, size and activity distributions by using aerosol diffusion spectrometer (ADS), diffusion battery and cascade impactor[1]. The range of ADS can be assessing from 10^{-3}µm to 10 µm. The number concentration of the injected aerosol particles is between (40-100) k particles/cm^3. The most item distribution of these particles within the ultra-fine particles (UFP) size range (0 to 0.2 µm) and the other in the size range from 0.3 to 1 µm. The surface and the mass size distributions are presented and compared with bi-modal distribution. In radon chamber, all distributions are clearly bimodal, as the free radon decay product is approximately at 1 nm in diameter with fraction ~ 0.7 for clean chamber (without any additional source of aerosols). The attached fraction with the aerosol particles from ECs has a size not more 1.0 µm.

Ref.

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P14

CALIBRATION SYSTEM UNCERTAINTY FOR RADON EEC MEASUREMENTS WITH SELF-ABSORPTION CONSIDERATION

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Th measurement of radon decay products level in dwellings or working places separately is not preferable. The estimation of radon equivalent equilibrium concentration (EEC_{Rn}) is more simple and quick technique. Alpha radiometry and alpha spectrometry are the most typical methods of EEC_{Rn} measurements. The influence of alpha particles absorption in filters and filter effectiveness should be taken into account. In a previous work [1], calibration system for radon EEC measurements is presented and described. Gamma spectrometer was used as a reference measuring device. In our work, the uncertainty of this system will be presented and the reduction will be suggested. The measurements of EEC_{Rn} by gamma spectrometry and improved alpha radiometry are in good agreement and the systematic shift between average values is observed and resolved.

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P15

VARIOUS APPROACHES FOR DETERMINING THE RADON POTENTIAL AND THEIR TESTING

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Radon and its progeny are well known for their adverse effects on human body; exposure to these radioactive elements is the second leading cause of lung cancer after smoking [UNSCEAR, 1982]. To address this issue, the EU member states shall establish national action plans addressing long-term risks from indoor radon exposures, and to identify areas where the radon concentration is expected to exceed the relevant national reference level [Euratom, 2014].

The regions where elevated indoor radon levels are expected for natural, i.e. geogenic reasons are called geogenic radon prone areas [Bossew, 2014]. Radon-prone areas can be identified either directly by using indoor measurements [WHO handbook, 2009], or indirectly from the properties of the upper layer of soil (radium and radon concentrations, porosity, soil type, permeability, water content, etc.). In this paper, several indirect approaches for determining the geogenic radon potential are compared on the area of Mochovce, Slovakia (~500 km^2), where important radiological characteristics of the soil (concentrations of ^{222}Rn, ^{238}U, ^{232}Th and ^{40}K) are well documented due to the presence of a nearby nuclear power plant [ŠGÚDŠ, 2018]. Although the maps of geogenic radon potential determined by these approaches are visually different due to different delineation of boundaries between the areas with low, medium and high radon potential, the correlation between numerical values of radon potential is high. These radon potential maps were then used to identify villages (Čifáre, Dolný Pial, Veľký Ďur) where elevated radon levels were suspected. In these villages, measurements of indoor radon were performed and evaluated.

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P16

THE CONTINUOUS MEASUREMENTS OF RADON EXHALATION RATE FROM SOIL IN SLOVAKIA

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Radon exhalation rate is influenced by a lot of varying factors, like physical and chemical characteristics of the soil, soil structure, ^{226}Ra content, emanation coefficient, permeability, soil humidity, variations of meteorological parameters (temperature, pressure, precipitation), and others. In this contribution, the results from continuous measurements of radon exhalation rate from soil in Slovakia are presented. Radon exhalation rate was determined using the AlphaGUARD, accumulation chamber and pump. The device was placed at meteorological garden of Faculty mathematics, physics and informatics, Comenius University in Bratislava, Slovakia. Our previous study show significant influence of precipitation on radon exhalation rate [1]. The influence of soil parameters (radon concentration in depth 0.3m; temperature and humidity soil in depth 0.05 and 0.3m) on radon exhalation rate is analysed in this study.
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P17

EXPLORATORY INDOOR ^{222}RN MEASUREMENTS IN RIOBAMBA CANTON

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Ecuador is divided into 220 cantons, these cantons are divided into urban and rural parishes. Riobamba canton is conformed by 11 rural parishes and 5 urban parishes. The urban parishes have approximately 157 thousand inhabitants while the rural area has 69 thousand inhabitants. Riobamba has been selected to carry out a pilot study on the radon concentration indoor in residential areas and schools.

The methodology used as reference, to determine the number of smapling dewelings, is the one proposed by Bocchichio and his collaborators [1,2], in addition certain modifications have been applied due to the particular characteristics of the area, such as, type of building material, building age, water supply, among others. The preliminary results shown a homogenous radon concentration, with certain anomalous behaviors, particularly due to the age of the building.

Two kinds of detector were used, E-perm electrets and a AlphaE ionization chamber. The maximum value found in the preliminary survey is 375 Bq/m^3 (5%) and the minimum is 20 Bq/m^3 (15%). In addition, the efective dose has been calculated, based on the average dose found for each parish belonging to the canton of Riobamba.

Ref.

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P18

FIRST SURVEY ON RADON CONCENTRATION IN MINERAL SPRING WATERS IN LAZIO REGION, ITALY

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In the last years, the requirements included in the Council Directive 2013/51/Euratom have led to an increase of radon concentration measurements in drinking waters. Even if the Council Directive, and so the Italian legislation, does not apply to natural mineral waters, two main reasons suggested the idea of monitoring mineral concessions. Italy is the first country in Europe for mineral water consumption, and besides, many mineral concession owners allow also consumers to fill bottles and containers, intended for transport and subsequent consumption, directly from the fountains within the plant.

The aim of the paper is to present methods and results of the first survey addressing the measurement of radon concentration in the mineral spring waters in Lazio region, Italy.

The measurements have interested 20 different mineral waters and have been carried out by using three distinct measurements chains, each composed by an ionization chamber detector, and a proper degassing circuit. The sampling was performed within the plants of the suppliers, directly from the fountains accessible to consumers. Two different sampling methods have been considered for each spring in order to evaluate if the containers filling methods could influence the dissolved gas degassing and consequently the measured radon concentration

The results show that 10% of mineral spring water sources returned radon concentrations higher than the parametric value, 100 Bq L^{-1} [1]. The sampling procedure slightly affects radon content, suggesting the relevance of containers filling methods in radon degassing. Previous studies referring to non-mineral waters of Lazio region [2] have been finally considered and compared to results of the survey.

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P19

LEVELS AND EFFECTS OF NATURAL RADIOACTIVITY IN SOIL AND WATER OF INDIAN HIMALAYAN REGION

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In this study, we report results of measurements of natural radionuclides (^{226}Ra, ^{232}Th and ^{40}K) that were carried out in Himalayan region of Uttarakhand state of India using a low level NaI*(Tl)* gamma ray spectrometer with the aim of investigating whether the exposure to these radionuclides pose a significant health risk to people. The activity concentrations of radon and uranium in potable groundwater samples were measured using semiconductor detector based RAD7 monitor and ICPMS technique, respectively. The descriptive statistics of ^{226}Ra, ^{232}Th and ^{40}K levels and associated hazard assessment quantities are given in the Table 1.

Table 1. Descriptive statistics of activity levels of primordial radionuclides and associated hazard assessment quantities

Hazard indices					Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K (Bq kg^{-1})			
H_{ex}	H_{ex}	H_{ex}	H_{ex}	Ra_{eq}	^{228}Ra	^{232}Th	^{40}K	
0.40	0.40	0.40	0.40	146	34.2 ± 4.43	28.7 ± 9.3	15.2 ± 3	Min
1.62	1.62	1.62	1.62	599	229 ± 23.4	295 ± 29.5	1360 ± 194	Max
0.87	0.87	0.87	0.87	322	97	129	541	AM
0.83	0.83	0.83	0.83	307	92	115	478	Median
0.83	0.83	0.83	0.83	306	87	119	365	GM
0.29	0.29	0.29	0.29	109	45	51	389	SD

The average values of ^{228}Ra, ^{232}Th & ^{40}K were found above the above the global average values of 35, 30 and 400, respectively given by UNSCEAR. The dose estimated using soil radioactivity was found in good agreement (parameters of linear fit: slope = 1.01, R = 0.98) with the ambient dose measured using portable survey meter. The radon concentration was found to vary from 2 to 198 Bq L^{-1} with an average of 35 Bq L^{-1}, the average value being higher than the safe limit of 11 Bq L^{-1} recommended by USEPA. The concentration of uranium was found in the range of 0.02 to 6.22 µg l^{-1} with an average of 1.26 µg l^{-1}, which is well below the safe limit of 30 µg l^{-1} recommended by WHO. The results of natural radioactivity levels in soil and groundwater are useful in radiation protection, geo scientific research and in establishing guidelines for the use.

Ref.

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P20

PRELIMINARY INVESTIGATION OF RADON CONCENTRATION IN SURFACE WATER AND GROUNDWATER IN SOME SUBURBS OF BEIJING

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In this study concentrations of radon-222 from 31 surface water and 30 groundwater samples collected during July 2014 from Miyun and Huairou county in Beijing, were evaluated in an effort to identify variations in radon-222 concentrations in different types of water. Then to classify potential radon exposure risk from groundwater. Furthermore, to analyze the relation between radon-222 concentrations in water and the local geologic lithology. Radon-222 is hereafter referred to as "radon." During the process of measuring surface water, the professional radon monitor AlphaGUARD PQ2000 PRO was applied, attached with special water measurement device. In the measurement of groundwater, we usually choose semiconductor continuous radon measurement instrument RAD7 with its accessory device RAD H_20. There are four types of surface water in this survey including river, reservoir water, water flowing in the approach channel and water in the mountain. Among that the average radon concentration of water samples in the mountain was 1.14 ± 0.08 kBq m^{-3} and the average radon concentration in other types of surface water was 0.09 ± 0.01 kBq m^{-3}. The groundwater samples for drinking were mainly from residents' tap water, namely water using terminal. The average radon concentration of the groundwater samples was 20.05 ± 1.75 kBq m^{-3} and the maximum and minimum value were 58.60 ± 6.28 and 2.53 ± 0.46 kBq m^{-3} respectively. Among that 22 groundwater samples collected in the regions were greater than 11.10 kBq m^{-3}, exceeding the limit of radon concentration level in drinking water stipulated by the national standard of China (GB5749-2006). In combination with the analysis of surrounding rock lithology we find that high water radon concentration values exist in volcanic rock, igneous rock and metamorphic rock whereas the water radon concentration values in sedimentary rock and quaternary sandy gravel are relatively lower. The average radon concentration of groundwater samples in above four types of rocks were 30.71 ± 1.32, 29.73 ± 2.64, 16.45 ±1.61 and 9.25 ±0.90 kBq m^{-3}, respectively. This shows that the groundwater directly contacting with the rock and soil will dissolve certain amounts of radioactive elements, so the radon concentration in groundwater will increase significantly. It is advisable to avoid drinking the groundwater without any disposal measures. Be on the safe side, it should be placed for a period of time, after that boiled for drinking.

Key words: Surface water; Groundwater; Radon concentration in water; Lithology

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P21

RADON IN KOWARIAN APARTMENTS

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Introduction. Kowary are located in the Jedlica River valley, between the Rudawy Janowickie and the Giant Mountains. The specific geological structure of this area caused the existence of underground mining in Kowary and its surroundings. The intensive development of the Kowarian industry took place in the nineteenth and twentieth centuries. Then intensified mining of iron ores, fluorite, zinc-lead ores, silver, copper and uranium takes place. The presence of uranium makes the Kowary area characterized by an increased concentration of radon in the air. Radon emanating from the ground tends to accumulate in enclosed spaces. Hence its presence in apartments, cellars, caves and other underground facilities. The occurrence of radon in flats is particularly interesting because of its negative impact on the human body.

Materials and methods. Measurements of periodic concentrations of radon in dwellings in Kowary were carried out by the Nofer Institute of Occupational Medicine three times. The first in 1995, the next in 1999-2000, and the last in 2015-2016. Trace detectors placed in closed dosimeters were used in the measurements [1]. The measurement lasted three months.

Results. In 1995, measurements were carried out in 14 flats, placing dosimeters mainly in rooms and kitchens. The maximum measured quarterly concentration was 680 Bqm^{-3}, and the average 150 Bqm^{-3}.

In 1999/2000 measurements were conducted in 21 apartments. The maximum concentration measured quarterly was 920 Bqm^{-3}, and the average 160 Bqm^{-3}. The measurements, repeated four times, also made it possible to calculate the mean annual concentrations of radon in the apartments. And so: the maximum annual concentration of radon was 490 Bqm^{-3}, and the average was 320 Bqm^{-3}.

The next, last measurements were carried out in the years 2015-2016 in 63 apartments. The maximum quarterly concentration was 1600 Bqm^{-3}, and the average 350 Bqm^{-3}. Annual concentrations were as follows: average - 260 Bqm^{-3}, and maximum 1100 Bqm^{-3}.

Conclusions. In relation to the first measurements, an almost twofold increase in the **quarterly** measured average concentration of radon in dwellings can be observed. This is most likely caused by changes in ventilation resulting from the use of modern but tight windows.

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P22

INDOOR RADON CONCENTRATION IN DWELLINGS OF THE WORKERS OF THE OLD URANIUM MINE OF URGEIRIÇA (CENTRAL PORTUGAL)

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The Urgeiriça mine was the main site of exploration of radioactive ores in Portugal. The operations began in 1913 and were concluded in the year 2000. During this period, a vein was explored through underground mining. Most of the ores explored in *ca.* 60 other mining sites were processed in the Urgeiriça facilities. This resulted in a high production of waste, which was accumulated in several tailings of this mining area.

Since 2001, the Portuguese government has been responsible for the environmental remediation works in the Urgeiriça area through the company EDM (*Empresa de Desenvolvimento Mineiro*). So far, around 30M€ have been invested only in the Urgeiriça area. In the early 1950s, two residential districts were built near the mining area by the English company who was, at the time, responsible for the mine (CPR), to provide support to the workers. During the environmental rehabilitation programme, research revealed the presence of radioisotope-enriched material in this dwellings, similar to those which were deposited in the old tailings. This prompted the creation of a rehabilitation programme for such dwellings, which is currently being implemented.

To assess radiological risk and ionising radiation exposure doses, radon gas concentration was measured in 124 homes using 493 passive CR-39 detectors. The project was carried out in two phases (P1 and P2), but the results were similar in both cases. Radon gas concentration in indoor air fell within the range of 46 to 6 094 $Bq.m^{-3}$. The arithmetic mean was 936 $Bq.m^{-3}$ (P1) and 742 $Bq.m^{-3}$ (P2), exhibiting high variability in both cases with coefficients of variation between 50 to 60%. Radon concentration is lower than 400 $Bq.m^{-3}$ in 30-40% of the measurements, and higher than 1 000 $Bq.m^{-3}$ in 20-30% of the detectors that were analysed.

The integration of this data with information obtained for other radiological variables made it possible to identify which dwellings required remediation, as well as the degree of intervention necessary for each one.

P23

EXPOSURES FROM RADON AND THORON PROGENY IN HIGH BACKGROUND RADIATION AREA IN TAKANDEANG, INDONESIA

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Radon has many isotopes with the most stable among them is ^{222}Rn (3.8 days) yet the shortest half-life is ^{220}Rn (5.6 seconds) which is called as thoron. Thoron is present together with radon and both of them are referred as the radon concentration in the environment while the amount of thoron is less than ^{222}Rn because of their half-life. Radon is known as the largest contributor to a background radiation dose measurement.

According to NCRP's (National Council on Protection and Measurement) report, more than 80% Radon and Thoron that was released into atmosphere originated from topsoil and the rest from other sources. The concentration of radon in the atmosphere varies, depending on the place, time and the height above the ground, the meteorological condition, the topography, house construction type, and even the life style of people [1]. Most of our time is spent within buildings; therefore, the measurement and limitation of radon concentration of buildings are important. The Environmental Protection Agency (EPA) estimated that 21,000 annual lung cancer deaths in the U.S. are attributable to radon and it is the leading environmental cause of cancer death in North America [2]. According to the EPA and the World Health Organization (WHO) Handbook on indoor radon is the second leading cause of lung cancer after smoking. The aim of this study is to estimate the exposures from radon and thoron progeny in high background area at Takandeang, Mamuju, Indonesia.

Takandeang District has 9 Area (Salumati, Taloba, Limbeng, Rante Dunia, Palada, Salubiru, Takandeang, Tabanga-banga, and Bettengkatta). The gamma ray background in Takandeang is around 0.338 μSv/h – 1.703 μSv/h. In this research, the measurements were conducted using passive-type radon-thoron detectors and thoron progeny detectors. That monitor was placed at 5 houses in each area for 1 month with 3 repetition from November 2018 to February 2019. The results of radon, thoron and thoron progeny was calculated as 66 ± 15 Bq/m^3 – 390 ± 53 Bq/m^3, 22 ± 12 Bq/m^3 - 598 ± 97 Bq/m^3, 6 ± 5 Bq/m^3 - 37 ± 23 Bq/m^3, respectively.

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P24

RADON ON GROUND FLOOR IN THE BUILDINGS OF PRE-UNIVERSITY EDUCATION IN MONTENEGRO

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In the framework of the national project MNE9005, funded by the International Atomic Energy Agency and the Government of Montenegro, radon was measured with passive dosimeters (Radosys, RSFV type) during the academic year 2016/17 (September − June) in the 2857 ground-floor rooms in 468 buildings of pre-university education in Montenegro - 344 buildings of primary and 42 of high schools, 5 buildings of the both primary and high schools, 67 kindergartens, 4 buildings of resource centers and 6 of student dormitories.

Average 9-month radon activity concentrations above the level of 300 Bq/m^3 were found in 728 rooms (25.5% of all sampled rooms), which belong to 213 buildings (45.5%), while in 111 rooms (3.9%) belonging to 47 buildings (10.0%) they were above 1000 Bq/m^3.

Radon activity concentrations in the Montenegrin educational buildings, averaged over all sampled ground-floor rooms of the building, range from 16 Bq/m^3 to 2810 Bq/m^3, with AM = 275 Bq/m^3. They follow closely a log-normal distribution (p = 0.92 by K-S test) with GM = 174 Bq/m^3 and GSD = 2.58. There are 135 buildings (28.8%) with average indoor radon concentrations on ground floor above 300 Bq/m^3, and 18 buildings (3.8%) where they are above 1000 Bq/m^3.

Influence of the nine factors (climate, urban/rural area, age of building, number of stories, building materials, basement, foundation slab, window frames, heating) on radon concentrations in the buildings were analyzed by univariate and multivariate method. Univariate analysis revealed significant relationship of the four factors - age of buldings, existence of basement, building materials and window frames, with radon concentrations on ground floor in the educational buildings, while multivariate analysis added to those factors urban/rural area and number of stories, but dropped building materials as a factor influencing significantly radon concentrations.

P25

RADON POTENTIAL MAPPING IN THE SOUTHERN CITYS OF CHINA

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Mapping the radon potential in China is a research project initiated by National Natural Science Foundation of China. Zhongshan City (ZC) was chosen one of the test areas. ZC is located in the southern part of China and bordered with Zhuhai City, a city with high radiation background. A preliminary radon survey in ZC was conducted using a portable semiconductor radon monitor RAD-7 and soil air permeability instrument Rad-jok, covering a total area of 1800 km2 with a grid of 10×10 km. The sampling depth for soil gas radon measurement in the field was at the depth of 80 cm below the ground.

Our preliminary radon investigations show that ^{222}Rn concentrations in soil gas varied between 0.74 and 158 kBqm^{-3}, and ^{220}Rn between 0.02 and 235 kBqm^{-3} in ZC. The average value of ^{222}Rn and ^{220}Rn was 67.6 and 74.8 kBqm^{-3}, respectively. ^{222}Rn mean value is one of the highest values in soil in the world.

Our survey shows that: (1) Characteristics and distributions of ^{222}Rn/^{220}Rn concentration in soil gas in ZC are obviously related with local lithology (the Middle and the Late Jurassic and the Cretaceous biotitic-granite) and geological formation. High ^{222}Rn/^{220}Rn concentrations in soil gas were observed in the outcrops of weathered granite or filled back granite sands. (2) The distribution model of ^{220}Rn is as same as that of ^{222}Rn. The radon potential map of ZC was made based on the radon concentration in soil gas and soil air permeability, combined with GIS technology. (3) The Wuguishan Mountain areas and in the south-east areas of ZC, covering with granite rocks, are high radon risk districts; the central zones in ZC are low radon potential areas, and part of the northern districts are medium radon potential areas.

The investigation suggests that we should pay attention to ^{220}Rn contribution in radon mapping in ZC because high ^{220}Rn would have a greater contribution to the inhalation dose to human beings.

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

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P26

RADON POTENTIAL, GAMMA RADIATION – PRELIMINARY RESULTS

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The aim of the research was to evaluate mutual relations between radon concentrations in the atmosphere; radon concentrations in soil; uranium, radium, thorium and potassium (K-40) contents in soil and gamma dose rates.

The survey has been carried out on granite bedrock in two regions: Strzelin Massif and Karkonosze Massif located in SW part of Poland. In each region 10 measurements points were established. The survey started in autumn and will be continued until summer in order to notice seasonal variations.

Radon concentrations in soil and in the atmosphere have been measured using SSNTDs Kodak LR-115. In the atmosphere the detectors were places 1.5 m above the ground and have been exchanged at the beginning of each season. In the soil the detectors were placed at least 0.5 m under the ground and have been exchanged twice during each season.

The contents of uranium (U-238), thorium (Th – 232) and potassium (K-40) in soil have been measured by portable Gama-Ray Spectrometer RS-320 BGO Super-SPEC twice during each season (in time, when radon detectors in soils were exchanged).

The gamma dose rates have been measured by radiometer produced by POLON-ALPHA. S.A which detects gamma radiation using the ionization effect produced in a Geiger–Müller tube. The measurements have been undertaken twice during each season (in time, when radon detectors in soils were exchanged).

Moreover, we took soils samples from a depth of 0.5 m in every measurement point. Each soil sample was dried and ground. The contents of Ra-226, Th-232 and K-40 have been measured in the laboratory using gamma spectrometric method. The uranium contents have been established using the radiochemical method.

The preliminary results revealed that the average values of contents of natural radionuclides in soil, radon concentrations in soil and in the atmosphere and gamma dose rates were higher in Karkoszone Massif than in Strzelin Massif. Although, in some points located in Karkonosze Massif those values were lower than in Strzelin Massif.

P27

NATIONAL COMPARISON OF METHODS FOR DETERMINATION OF RADON IN WATER

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Intercomparison experiments concerning radon ^{222}Rn determination in water samples prepared in laboratory were carried out at the Laboratory of Radiometric Expertise (LER), Institute of Nuclear Physics, Polish Academy of Sciences in Kraków. Most of the institutions dealing with such measurements in Poland participated in the experiments. They are gathered in the Polish Radon Centre. The goal of these exercises was to evaluate different measurement techniques used routinely in Polish laboratories.

The first experiment was performed in March 2014. Six laboratories participated in this experiment. LER provided two different 222Rn activity concentrations: 1) 69.5 Bq/L and 2) 12.3 Bq/L. All laboratories used the liquid scintillation counting (LSC) method but with different instrumentations. Two of them also used the AlphaGuard ionization chambers based on alpha spectrometry. The participants sent their reports containing the description of the method and the results with the uncertainties. The report prepared by LER allowed the participating laboratories to improve their measurement methodologies and to achieve better, i.e. more convergent results of determining radon concentration in water samples.

The second experiment was performed in March 2018 and the report was prepared in July 2018 by LER. Nine laboratories participated in the second experiment examining once again different types of LSC and AlphaGuard ionization chambers. As previously, LER provided two different radon activity concentrations with the robust values equal to 1) 4.08 Bq/L and 2) 27.05 Bq/L. The criterion for evaluating the results of each participant was based on the analysis of the *Z-score* value, similarly to the first experiment.

There were two main conclusions coming out from the exercises. The one concerns the choice of the best measurement method. The results show that with LSC instruments one can obtain low detection limits, good accuracy and precision for determining radon. The second conclusion concerns the tests and improvement of water device built by LER. Both subjects will be discussed in the presentation and publication.

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RADON INTERCOMPARISON TESTS - KATOWICE 2016

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At the beginning of the year 2016 the representatives of Polish Radon Centre decided to organise the proficiency tests for radon and radon decay product monitors and methods.

The Silesian Centre for Environmental Radioactivity of Central Mining Institute (BCR), Katowice, became responsible for the organisation of PT exercises. Main reason was the radon chamber in BCR with the volume 17 m^3, constructed on the base of the climatic chamber of Feutron company.

The information was spread throughout Poland and finally 13 participants from the country expressed their access plus one participant from Germany. The participants have been invited to inform organisers, what types of monitors and methods thys would like to check during tests.

On this basis the BCR team prepared the proposal of the schedule of exercises, like required level(s) of radon concentrations, number and periods of tests, proposed PAEC levels and also the overall period of PT. Participants informed organisers of the availability of radon calibrated sources (Pylon company), on this basis three sources with different Ra-226 activity were chosen for exercises.

The PT activity was performer between 6 until 17 of June 2016. Results of measurements from participants have been collected till October 2016, but the analysis of results shown a significant problems, related to the reference activity of applied Pylon sources. In case of 2 sources (out of 3), the activities of radon in the chamber differed from the calculations. Therefore the modification of preliminary approach was necessary. After recalibration of results the agreement between radon monitors and other measurements methods was confirmed.

In case of PAEC monitors and methods the results of PT exercises were consistent and confirmed accuracy of calibration procedures, used by participants.

P29

A NEW PORTABLE RADON PROGENY MONITOR USING A SILICON PHOTODIODE

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International Commission on Radiological Protection (ICRP) recommended a new dose conversion factor for radon according to the latest epidemiological studies and dosimetric modeling [1]. It is getting important to evaluate an inhalation dose from radon and its progeny, especially for workers in the cave. However, most of the commercially available radon progeny monitors are large to carry and expensive. In the present study, a new portable radon progeny monitor was developed using an inexpensive silicon photodiode and continuous air sampling, and the performance test was carried out.

A developed radon progeny monitor is composed of a collection part and a detection part. In the collection part, radon progeny in the air is collected on the membrane filter installed in an open-faced filter holder by using a pump. The alpha and beta particles from radon progeny are detected by the silicon photodiode which faces the filter holder with a continuous air sampling. The Equilibrium Equivalent Radon Concentration (EERC) is calculated by counts of alpha particles from ^{218}Po and ^{214}Po using an algorithm [2].

The performance test was carried out at a tourist cave in Okinawa and a volcanic area in Kagoshima. EERC was evaluated, and radon concentration was simultaneously measured by an ionization chamber AlphaGUARD as well. The EERC in a tourist cave and a volcanic area ranged from 2.5 to 12 Bq m^{-3} and 0.63 to 5.0 Bq m^{-3}, respectively. The results indicate that the developed monitor can measure an EERC of 1.0 Bq m^{-3} if the relative standard uncertainty of 20% is permissible.

In this presentation, the detailed results of the performance test will be reported.

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P30

INDUCED RADIOACTIVITY IN THE EYE TREATMENT ROOM AT CYCLOTRON CENTRE BRONOWICE FACILITY

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Cyclotron Centre Bronowice (CCB) is the first proton radiotherapy facility operating in Poland. Since 2016, therapy is performed using isochronic cyclotron Proteus C-235 which is capable of producing protons of energies up to 230 MeV. Among other types of cancers, an eyeball cancer is treated with proton radiotherapy at CCB on a regular basis.

The treatment of ocular cancer is performed in the eye treatment room using 70 MeV protons. During the whole treatment process patient is seated in the robotic chair and protons are delivered to the tumor located in the patient's eyeball through a specific beam delivery system.

Apart from the initial proton radiation, some induced radioactivity will appear in the process, mainly due to various nuclear reactions of incident protons with the materials of different objects that are placed on their path to the tumor. Those reactions can produce isotopes that emit gamma rays that can introduce additional radiation dose to patient and more importantly to the facility staff.

The aim of this work was to thoroughly investigate the phenomenon of inducing radioactivity in the eye treatment room at CCB. The series of gamma dose rate measurements in different spots of the treatment room and at different points in time were performed. Moreover, series of gamma spectrometry measurements of different parts of the beam delivery system were carried out as well.

The results have shown that specific parts of the beam delivery system, i.e. range modulator, nozzle and beam stopper are the ones that get activated the most during the process of irradiating patients and conducting calibration tests. In both range modulator and beam stopper ^{7}Be, ^{11}C and ^{13}N isotopes were found. The latter two of these were the most abundant, thus they contributed the most to their gamma dose rate, but at the same time the dose rate levels were rapidly decreasing due to short half-life values of ^{11}C and ^{13}N (20 and 10 minutes, respectively). In the case of nozzle, a lot more isotopes have been produced with ^{60}Cu, ^{60}Cu, ^{62}Zn, ^{63}Zn and ^{66}Ga (which are rather short-lived, half-life values of these nuclides range from 24 minutes to 9,5 hours) being the most abundant. Some long-lived isotopes, like ^{58}Co and ^{65}Zn have been generated as well, which makes handling the nozzle in a safe manner not only a short-term but also a long-term important issue to deal with.

The studies that have been carried out clearly indicate that induced radioactivity is a non-negligible phenomenon in terms of proton radiotherapy. This research has also already been successfully extended to other treatment and experimental rooms in CCB facility.

P31

A SORBEN-TEC SYSTEM FOR RAPID DOSIMETRIC EVALUATION OF RADON LEVEL IN DRINKING WATER

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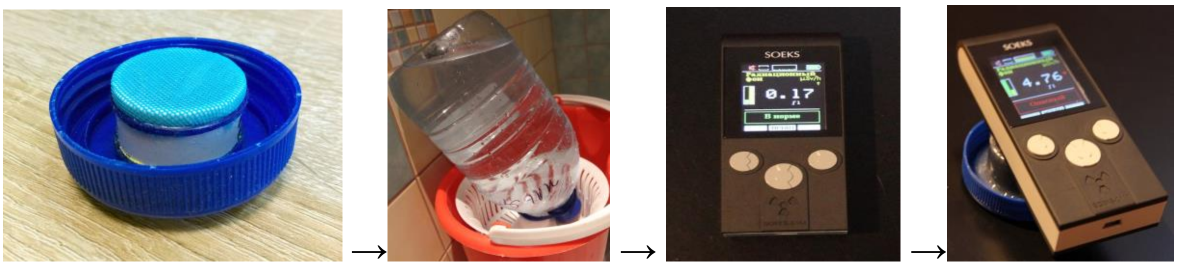
A number of instruments based on direct gamma ray spectrometry (scintillation and semiconductor detectors), emanometry (ionization chambers, lucas cells) and liquid scintillation counting are used for radon determination in drinking water [1]. These methods provide low detection limits, from 0.05 Bq L^{-1} for liquid scintillation counting to a few Bq L^{-1} for gamma ray spectrometry, but they require expensive equipment and can be performed only in specialized laboratories. EKSORB Ltd (Russia) has developed and patented a Sorben-Tec system (see Figure) for rapid evaluation of ^{222}Rn in drinking water using a common domestic dosimeter or beta radiometer [2]. The system consists of a bottle cap with a little plastic sorption column attached. The use of the Sorben-Tec system for rapid evaluation of ^{222}Rn level in drinking water is possible due to the sorption of beta and gamma emitting short-lived decay products of radon. Five different sorbents were tested in this system. All experiments were performed using natural underground water samples containing ~ 10, 100 and 1500 Bq L^{-1} of ^{222}Rn. It was shown that the system with the E214 sorbent (iron hexacyanoferrate based on cellulose) provided detection limits of radon in 5L water samples of 35 – 40 Bq L^{-1} and around 10 Bq L^{-1} for dosimetric and radiometric measurements respectively. This detection limit is quite enough to identify drinking waters having dangerous radon levels. The total time of analysis is approximately one hour excluding sample storage for short-lived decay products ingrowth (min. 3-5 hours). The E214 sorbent provided sorption of both ^{214}Pb and ^{214}Bi, thus increasing sensitivity, whereas the degree of radon sorption was insignificant. Thus, the Sorben-Tec system is suitable for rapid domestic radiation safety assessment of drinking water.



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P32

CALIBRATION OF A GROUNDWATER-RADON MONITORING STATION FOR SEISMIC PRECURSOR STUDY

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A groundwater-radon monitoring station is in operation at Gallicano, a thermomineral spring located in Garfagnana, a high seismic area in Tuscany (Italy). The station automatically and continuously measures the radon concentration of the groundwater, and then transmits online the data to a dedicated web page [1]. Radon monitoring is performed along with the measurement of some geochemical parameters of the water, done by another dedicated station which operates together with the previous one, and belongs to a wider geochemical monitoring network operating in Tuscany since 2002 [2]. The purpose of these two stations is examining possible correlations between radon levels and geochemical parameter anomalies before an earthquake.

The radon station measures the radon concentration in groundwater by means of gamma spectroscopy with a 2"x2" NaI(Tl) scintillation detector, analysing groundwater samples drawn into a Marinelli-type container after equilibrium is reached between radon and its short decay progenies. The energy and efficiency calibration of the scintillator detector is performed using a radon source with known radon concentration, placed inside a Marinelli beaker like the one used in the station.

In this work, an independent verification of the efficiency calibration of the radon station is obtained by an intercomparison with the liquid scintillation counting of radon in groundwater, considering the same water sample as that one of the station. Prior to the measurements, a precise determination of the efficiency of radon counting with the liquid scintillation spectrometer was determined by measuring a set of calibrations vials [3]. The vials contained ^{226}Ra standard solution diluted with distilled water and organic scintillation cocktail. ^{226}Ra activity concentration covered the anticipated activity range of the samples to be analyzed.

An accurate knowledge of radon concentration is mandatory to validate the acquired data series and to identify possible anomalies with respect to the radon average value and correlations with the geochemical parameters of the water. When an anomaly is identified, after removing all the other possible causes of radon concentration variation, this may be considered as a possible index of variation of the seismic activity.

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P33

DESIGN, CONSTRUCTION, AND COMPLETION OF AN ACCUMULATION CHAMBER WITH CONTROLLED CONDITIONS FOR STUDIES OF RADON EXHALATION FROM BUILDING MATERIALS

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The indoor radon concentrations mainly depend on radon exhalation from surrounding soil and from building materials. It has been shown that radon exhalation from building materials is the main source of radon in upper floors of buildings. The structural properties of the materials, such as porosity and permeability, significantly influence the rate of radon exhalation rates. However, there are other environmental factors, such as temperature and humidity, whose effects should be studied according to the particular characteristics of building materials and the climatic environmental conditions. To guarantee reliable and quality results, it is necessary to standardize the experimental procedure both to measure radon exhalation and to control environmental parameters to achieve the desired study. To perform such studies and obtain reliable results, it is required to have a chamber with special characteristics.

This paper presents the design and construction of a radon accumulation chamber where temperature and humidity are controlled. In its design, the radon exhalation study of a material in both natural and processed form is considered. Radon exhalation rates are calculated from radon concentrations measured by a continuous monitor inside the chamber working in diffusion mode. Radon leakage from the chamber is negligible. The temperature inside the chamber can be controlled through a user interface in the range of 13 °C to 35 °C, with an overshot of 2°C. The relative humidity inside the chamber can be controller in a range of 99% to 50% with an overshot of 2%. The spatial distribution of the temperature was studied and the influence of humidity on its spatial-temporal behaviour was evaluated. The delay time between the fixed temperature value and the current value inside the chamber was about 2.5 seconds.

Guidelines for a standard experimental protocol are advanced and a tentative classification of building materials is proposed based on radon exhalation rates required to reach legal indoor radon action levels in Peru.

P34

A DIRECT $^{220}Rn/^{222}Rn$ PROGENY DETECTOR USING A THEORETICAL METHOD

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Presently, the evaluation of internal exposure to radon and thoron doesn't directly use the radon and thoron concentration instead of the equilibrium and equivalent concentration (EEC). However, the equilibrium factor is depended on many parameters, such as the radioactive decay, ventilation, reactions with the structure, and its furnishings. Since the short half-life of thoron (55.6 s), the indoor thoron concentration distributes heterogeneously, decreasing with the distance from the source. Therefore, it is not feasible to use the thoron concentration directly measured by the integrating monitors to evaluate internal exposure. The direct measurement technique of radon and thoron progeny is desirable and necessary for the evaluation of internal indoor radon and thoron exposure.

Recently, the direct radon and thoron progeny measurement technique for EEC of radon and thoron was developed by Tokonami *et al*.[1], Mishra and Mayya[2]. The key point of this technique is the estimation of the effective deposition velocities of combinations of radon and thoron progenies in a typical indoor environment. Some researchers used the experimental method to estimate the geometric mean deposition velocity and applied the data to the actual measurement in the indoor environment. However, the experimental conditions have a lot of limitations of environmental parameters for estimation of the deposition velocities. In this research, we developed a novel direct radon and thoron progeny detectors by the stainless-steel plate, CR-39, and aluminum-vaporized Mylar film with 3 channels, which can only detect the alpha particles emitted from responding progeny radionuclides. In addition, a theoretical method combined Lai-Nazaroff formula and Jacobi room model was used to estimate the deposition velocities, EEC and the concentration of the short-lived progenies. A sensitivity analysis of the parameters was carried out to analyze the impact factor for this model. As a result, the theoretical method can consider the changes of the environmental parameters during the calculation process, and the friction velocity is found to be the most important environmental parameter for this model. More work is needed to clarify the mechanism of aerodynamic condition with the deposition velocity in both the indoor environment and experimental condition.

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P35

$^{214}Bi/^{214}Pb$ RADIOACTIVITY RATIO THREE YEARS MONITORING IN RAINWATER IN PRAGUE

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Continuous monitoring of radioactivity ratio of $^{214}Bi/^{214}Pb$ as tracers in rainwater was carried by several reserchears[1,2] to study their concentration variations. During atmospheric thermal inversions, there is an increase of concentration of natural gamma emitting radionuclides of the short-lived ^{222}Rn progeny (^{214}Pb and ^{214}Bi with half-lifes of 26.9 min and 19.9 min respectively), that causes an increase in the total natural gamma background. This Radon progeny is incorporated in the raindrops and dragged to the ground. Such events have been recognized as obstructive factors in monitoring artificial radionuclides and natural environmental radioactivity[3]. Related to this phenomenon, Radon variability attributable to diurnal changes in atmospheric mixing of the overall variability in ambient gamma dose contribute less than during precipitation periods.

In this framework, three years time series of continuous monitoring (1 min time interval) of equivalent dose rate per hour (Dh), meteorological parameters and gamma spectrometry in air are investigated. Measurements are carried out on the roof of the Faculty of Nuclear Sciences and Physical Engineering of the Czech Technical University in Prague (ČVUT) by using an instrument of the Czech company NUVIA having a 3×3" NaI(Tl) gamma probe. The counting rates of the 352 keV and the sum of the 609 keV and 1120 keV gamma ray peaks were selected for measuring the ^{214}Pb and ^{214}Bi activities concentration, respectively. An hybrid forecasting method composed by Multiple Linear Regression+Empirical Mode Decomposition+Support Vector Regression[4] is applied for the time series analysis to identify anomalies in the $^{214}Bi/^{214}Pb$ signal and to correlate them with the equivalent dose rate (μSv/h) and with amount of rainfall (mm/h). The results show correlation between the Dh and $^{214}Bi/^{214}Pb$ anomalies with rainfall ≥ 5 mm/h. Furthermore, it is shown that the considered progeny of Radon is the main responsible for the overall adsorbed equivalent dose.

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"Radon measurements: calibration, quality assurance and measurement protocols"

Regulatory requirements on the quality of radon measurements
*(Thomas **Beck**, Federal Office for Radiation Protection, Berlin, Germany)*

Accredited methods - how to maintain high quality of radon measurements?
*(Jadwiga **Mazur**, Institute of Nuclear Physics PAN – Kraków, Poland)*

The accreditation of research methods confirms the high level of research and the reliability of results. Meeting the requirements of ISO Standard 17025 is connected with demonstrating the laboratory's competence in conducting measurements. An important element of these competences is the participation and/or organization of inter-comparison measurements. Our Laboratory's research on preparation of radon in water standard for inter-comparison measurements as well as the plans for future investigation will be presented.

A comprehensive quality control system for track etch analysis
*(Erik **Hulber**, Radosys Ltd. – Budapest, Hungary)*

Over 40 track-etch radon measurement systems with track readers and etching instrumentation work at laboratories in Europe, many of them with ISO-17025 accreditation. In order to meet the requirements well developed quality control system is needed both for the radon detectors and the operation of the analysis equipment. It is scientific challenge to achieve the trade-off between productivity and metrology efficiency. Suggested concept is presented by the paper while practical solutions are illustrated by QC statistics and verified structures.

Radon adsorption in detector holder plastic – a source to incorrect calibrations
*(Tryggve **Rönnqvist**, Radonova Laboratories AB – Uppsala, Sweden)*

It has been found that a large amount of radon can be adsorbed in the plastic of the detector holders to alpha-track detectors. Even after 24 hours of outgassing, the main part of this adsorbed radon remains and could give additional exposures if the detectors are put in sealed bags after the outgassing. This effect has been studied in detail for different detector holder types and it will be discussed how much this could affect calibration exposures if the handling involves sealing the detectors in bags after outgassing.