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LABORATORY of RADIOMETRIC EXPERTISE
INSTITUTE of NUCLEAR PHYSICS PAN

The Henryk Niewodniczanski
INSTITUTE of NUCLEAR PHYSICS
Polish Academy of Sciences

BOOK of ABSTRACTS

INTERNATIONAL CONFERENCE

Edited by
Jadwiga Mazur (IFJ PAN, Poland),
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Foreword

The Henryk Niewodniczanski Institute of Nuclear Physics, **Polish Academy of Sciences** has been organizing since 2000 the serial conferences, traditionally called RADON IN ENVIRONMENT. This is the first international meeting, two previous conferences (in 2000 and 2005) were national.

The conference covers the following topics:

- *radon and thoron in air, water and soil,*
- *modelling of radon transport,*
- *geological aspects,*
- *measurement techniques and interpretation of results,*
- *techniques of reducing radon concentrations,*
- *health aspects,*
- *protection against radon risk,*
- *uranium and thorium series,*
- *NORM and TENORM elements in environment,*
- *law regulations,*
- *information policy.*

The Conference takes place in Zakopane (southern part of Poland, about 100 km distance from Krakow) at the conference and holiday centre "ANTAŁÓWKA".

Zakopane, beautifully situated at the foot of the Tatra mountains, offers a chance to take advantage of outdoor recreation and to become acquainted with the unique folklore of the local mountaineers.

We do hope that the conference will provide a forum to explore and discuss new scientific initiatives and all participants will benefit from this meeting.

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ORAL PRESENTATIONS

Invited Talk

SLOVENIAN APPROACH IN MANAGING EXPOSURE TO RADON AT WORKPLACES

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Within the second stage of the Slovene national radon survey, carried out in the period 1998–2008, radon (^{222}Rn) activity concentration in air was measured at a variety of workplaces, using various complementary devices: alpha scintillation cells to analyse grab samples, etched track and electret detectors to obtain time-averaged concentrations, and electronic instruments to monitor radon continuously (with the Genitron's AlphaGuard and the Sarad's EQF, RTM and RadonScout devices). Diurnal variations of the measured parameters have thus been followed.

The environments studied have been those on the surface, such as kindergartens, schools, hospitals, spas and some other selected public buildings, and those underground, such as water supply plants, wineries and karst caves. Based on radon concentration (C_{Rn}), taking into account averages over both the entire time and working hours only, effective doses (E_{eff}) of the employees were calculated using DCF_{E} = 5 mSv WLM^{-1} as the dose conversion factor calculated from epidemiologic studies and recommended for workplaces by the International Commission on Radiological Protection. In addition, dose conversion factors (DCF_{D}) were also calculated, based on the measured fraction (f_{un}) of the nano-size, unattached radon decay products and applying the dosimetric models. These are compared with DCF_{E}. In the paper, C_{Rn}, f_{un} and E_{eff} values at various workplaces are reported and discussed.

Invited Talk

RETROSPECTIVE ASSESSMENT OF ENVIRONMENTAL RADON EXPOSURE

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The accurate assessment of radiation exposures is an important component of radiation epidemiological studies. This is difficult to achieve, as in most of the cases the radiation measurements were not made at the time of exposures. Radiation exposure and dose assessments of Hiroshima and Nagasaki bomb survivors are good examples of the former situation while those of many underground miner cohorts exposed to radon (^{222}Rn) and its progeny are examples of the latter. In recent years, a number of major case-control epidemiological studies on lung cancer incidence in the general public exposed to radon in their homes have taken place or are in progress. In most of the epidemiological studies contemporary radon measurements have been used as surrogates for radon concentrations in past decades even though changes in radon levels and residence may have occurred. Since radon concentrations fluctuate, sometimes wildly over days and weeks, a measurement that only captures the radon concentration over a few days time is not very reliable in estimating a person's long-term risk from radon related exposure. Keeping in view this gap, there is a need of a reliable technique for assessment of radon exposure in past.

Retrospective technique can reconstruct the average radon concentration for periods of as long as several years. These past radon and radon progeny concentrations can be reconstructed from the indelible record left on glass by radon exposure. Airborne radon decay products can be deposited and implanted through alpha recoil into the glass surfaces. On glass surface, activities of ^{210}Po may arise as a result of the decay of recoil implanted activity following the alpha decay of surface deposited ^{218}Po or ^{214}Po. Measurement of ^{210}Po implanted on a household glass is a method that can be employed to retrospectively determine the historic level of radon in dwellings. This method is based on the assumption that levels of recoil-implanted ^{210}Po in the glass provide a measure of time integrated radon concentration in the environment in which the glass has been located. The surface deposited activity of the radon progenies, which then become implanted in the glass by alpha recoil, is believed to reflect past exposure to airborne activity. Such retrospective measurements on glass are valuable in estimating the human dose derived from radon during the time of exposure. In this paper an account is given of the principles and some field applications of a retrospective technique, using the alpha track detectors, CR-39 and LR-115, to measure ^{210}Po implanted in glass surfaces (surface traps). By using this CR-LR difference technique, the cumulative radon exposure in a dwelling in past decades may be estimated. This method provides reliable radon exposure data as a support to epidemiological studies concerning the health effects of radon exposure in the living environment.

Invited Talk

IMPORTANCE OF THORON (^{220}Rn) IN RADON (^{222}Rn) STUDIES

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Radon (^{222}Rn) is internationally noted as the second cause of lung cancer. Thus many countries are about to solve the problem worldwide. Since recent studies have revealed that a new evidence of lung cancer risk is found out with a low level below 200 Bq m^{-3}, the reference level will have to be set lower than before. The ICRP will revise the dose conversion factor based on such scientific findings. Therefore, importance of radon exposure has been further recognized and accurate radon concentrations will be required. Recently thoron (^{220}Rn) has also been recognized from the viewpoint of accurate radon measurements. In addition, exposure from thoron decay products will have to be considered in the near future. The present study summarizes the followings [1-10]:

1. QA/QC (NIRS radon and thoron chambers, intercomparison)
2. Measurement techniques for thoron and its decay products
3. Field data and dose assessment
4. Other research topics in our research team

Ref.

[1] Tokonami, S. et al.: *The American Institute of Physics (AIP) Conference Proceedings Series*, 1034 (2008), pp. 145-148.
[2] Tokonami, S. et al.: *The American Institute of Physics (AIP) Conference Proceedings Series*, 1034 (2008), pp. 202-205.
[3] Sorimachi, A. et al.: *The American Institute of Physics (AIP) Conference Proceedings Series*, 1034 (2008), pp. 206-209.
[4] Ishikawa, T. et al.: *The American Institute of Physics (AIP) Conference Proceedings Series*, 1034 (2008), pp. 423-426.
[5] Sorimachi, A. et al.: *Review of Scientific Instruments* 80, (2009), pp. 015104.
[6] Ishikawa, T., Tokonami, S. and Nemeth, Cs.: *Journal of Radiological Protection*, 27 (2007), pp. 447-456.
[7] Sorimachi A. et al.: *Radiation Measurements*, 44 (2009), pp. 111-115.
[8] Kranrod C. et al.: *Applied Radiation and Isotopes* (in press).
[9] Yasuoka Y. et al.: *Journal of Radioanalytical and Nuclear Chemistry* (in press).
[10] Hosoda, M. et al.: *Review of Scientific Instruments* 80, (2009), pp. 013501.

Invited Talk

RADON AND ENVIRONMENTAL GAMMA RADIATION INVESTIGATIONS IN SERBIA - RESULTS OF INTERNATIONAL COLLABORATIONS IN THE PERIOD 1993-2009

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During the period 1993-2009, as described in the published scientific papers, a series of field investigations into radon exposures were carried out in Serbia. This work was in collaboration with a number of international research teams or researcher themselves from Ireland, Greece, Norway, Japan , Belgium, Russia, Poland, Italy, Sweden, Slovenia, India., Germany, Albania, Austria. Of particular interest was the assessment of the exposure of the general population to high levels of indoor radon at number of locations in Serbia and Republika Srpska (Bosnia and Hercegovina).

In addition to making contemporary radon measurements using Cr-39 nuclear track detectors for the first time in this region retrospective radon assessment methods and techniques were used to determine radon levels in past decades. Furthermore, indoor thoron measurements were made in a number of field locations using Japanese passive discriminative polycarbonate as well as Japanese CR 39 passive discriminative nuclear track detectors. This was also an innovation in this region. Indoor radon levels in excess of 6000 Bq/m^3 were found to be present in two of the investigated areas namely: Niska Banja and Gornja Stubla.

The geological/geochemical origin of these high radon levels was identified in this work showing that the entry of soil gas into the dwellings is the main contributor to indoor radon levels. The radon/thoron soil gases examinations were also provided at some field locations for the first time as well the comparison of their distribution at low and high background areas. Quite challenging were examinations of the thermo mineral water samples on radium content. Naimly, Radium in water could indicate indoor radon problem in the region and water investigation is useful at initial stage of radon survey. Even low Ra-226 concentration in water (0.1-0.6 Bq/dm^3) caused high Ra-226 activity in travertine (<1500 Bq/kg) that resulted in indoor radon concentration above 2000 $Bq{\cdot}m^3$ as measured in Niska Banja.

Outdoor radon and gamma activities were obtained for the most of the field sites dealing with indoor radon investigations. All results gave the opportunity for the comparison of the methods and techniques as well as the field areas which were thoroughly presented at two international workshops, i.e., "Promotion of New Electrochemical Etching Facility (ECE) and Its Applications to Natural Radiation Studies in Western Balkan Counties " (ECE I) and "The second Vinca ECE Lab advanced research international workshop- the new perspectives for thoron survey and dosimetry" (ECE II) initiated by ECE Lab, Vinca Institute, organized and held in 2003 (Beograd) and 2005 (Niska Banja) years in Serbia . These findings have formed the basis for the planning of further work in these areas, currently the establishment of radon risk map over Serbia being the part of potential European radon atlas.

Using current exposure/dose conversion factors from the ICRP (International Commission on Radiological Protection) levels as high as 6000 Bq/m^3 means that occupants of such dwellings may be receiving annual effective doses in the range 100 to 150 mSv per year. This is well in excess of the permitted annual effective doses to occupationally exposed workers in the nuclear industry, scientific institutes, hospitals etc. While such doses from natural radiation in homes are not subject to regulatory control the harmful health effects, in particular the induction of lung cancer, due to such doses should be a matter of public health concern. Because of the small populations in these areas it would be very difficult to conduct epidemiological studies of sufficient statistical power to directly demonstrate the health effects. Radon is, however, already classified by the UN agencies IARC (International Agency for Research on Cancer) and the WHO (World Health Organization) as a Class 1 carcinogen placing it in the same class as asbestos, benzene, arsenic etc. This should mean that exposures to high levels of radon should be reduced without the need for new epidemiological studies. Therefore it is concluded in this work that strategies can and should be developed for these areas aimed at reducing future exposure to indoor radon. Experience in other countries has shown that the most effective way to reduce the health burden from radon is to introduce new building regulations and practices in affected areas which will reduce the entry of soil gas radon (which is the main source) into the internal airspaces of dwellings. Improved foundations, sub-floor ventilation, radon impermeable membranes etc are inexpensive and effective methods to ensure radon levels in new houses are reduced compared to historical levels in an area. For existing dwellings these techniques can also be used but are more expensive to install. Finally it can be said that the identification and assessment of the health aspects of these high radon areas in Serbia is potentially a significant contribution to the improvement of public radiological protection in the country and elsewhere.

A1

HISTORY OF RADON MEASUREMENTS AT THE INSTITUTE OF NUCLEAR PHYSICS PAN, KRAKÓW, POLAND

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The brief history of radon measurements conducted at the Henryk Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences (IFJ PAN) in Krakow is presented. This history includes the period from 1983 till now. During those years a development of methods, equipment and skills of staff involved in research can be observed.

Radon investigation at IFJ PAN started in 1983 with indoor radon measurements, performed together with CLOR Warsaw, using LR-115 track detectors placed in NRCB diffusion chambers. In 1984-1989 a set of methods for radon and progeny concentration measurements in dwellings and mines, based on self-made thin-layer $CaSO_4$:Dy TL detectors, were developed. The detectors are still applied for routine measurements of radon concentration in Polish coal mines. (T.Niewiadomski, E.Ryba).

Then the technique of charcoal canisters was implemented both for indoor radon and for radon exhalation rate from soil (J.Łoskiewicz). In 1996 the professional radon monitor Alpha GUARD (by Genitron GmbH) was purchased – it was the first such device in Poland.

The significant progress ensued in 2001 when a separate laboratory (head dr K.Kozak) for natural radioactivity measurements (including research on radon) was formed at IFJ PAN.

Now IFJ PAN owns, among others, three AlphaGUARD monitors, RADOSYS – automatic system for etching and reading CR-39 detectors, liquid scintillation counter TRIATHLER 3, radon calibration chamber with certified radon sources, WLx – system for radon and thoron progeny measurements. The mobile laboratory CHIMERA Lab. (funded by UE) makes it easier to carry out field measurements in different regions.

A2

PASSIVE RADON-SAMPLERS BY SOLIDS WITH NANOHOLES-
I. The radon-badges for solving problems of passive monitors

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The first passive radon monitor was termed radon film-badge by Geiger in 1967 [1], in analogy with the neutron- and gamma-film-badges. This monitor, instead of a radon film-badge, should be considered the first diffusion chamber, the principle of which has been exploited in all existing passive radon-monitors [2].

In the present paper, a truly radon film-badge is finally proposed, which is formed by a thin-film radiator with suitable radon-sorption characteristics, facing a track detector. At the nanometer scale, the sorption processes can be explained in terms of the nanoparticles formed by the radon atoms, being enclosed in bulk-distributed nanoholes (absorption) or surface-distributed nanoholes (adsorption).

When compared with existing passive radon monitors, these radon film-badges present several advantages, such as:

- unique compactness,
- wide linearity of response (from 100 times less to 10 times more than that of existing monitors),
- any desired response sensitivity, suitable for one-week-measurements in dwellings up to one-year-integrated measurements in caves.
- correct and convenient soil-radon measurements,
- directly-in-water radon measurements.

Ref.

[1] Geiger E. L.: *Radon film badge*; *Health* Physics 13(1967), pp.407-411.

[2] Tommasino L.: *Personal dosimetry and area monitoring for neutrons and radon in wo*rkplaces; Radiation Measurements 34(2001

A3

PASSIVE RADON-SAMPLERS BY SOLIDS WITH NANOHOLES- II. The use of a pancake Geiger-Muller for radon measurements

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Since radon and radon decay products emit all types of radiation, the whole spectrum of radiation detectors could be used for radon monitoring, but most methods consist in detection of alpha particles, some are based on detection of gamma emissions, while only a few utilise beta decays.

However, beta-contamination monitors are widely used for routine radiation protection by radionuclide laboratories, and for emergency response by fire brigades and civil-defence-departments. All these monitors are of little or no use for radon measurements. On the other hand, most of the instrumentations used for the measurements of radon and its decay products is not useful for the measurements of man-made radionuclides.

It was Von Philipsborne (1), who first pointed out the importance of using beta-contamination monitors both for the natural and man-made radionuclides.

In order to be able to use these monitors for the measurements of radon gas and its decay products, it is necessary to gather these radionuclides onto large solid surfaces.

To this end, we have developed four novel passive sampling-methods, two of which are for radon and other gases, while the remaining two are for radon decay products and other radioactive particulates. These 4-samplers system (termed quatrefoil) transforms the airborne radionuclides into surface-bound radionuclides.

Only two sampling methods will be reported, which are dealing with the collection of radon only-gas onto solid-material surfaces, as described in the first part of this paper. These new approaches for radon sampling and detection make it finally possible to carry out measurements, which are difficult, if not impossible, to carry out with existing technologies.

In particular, the present paper reports applications of these new samplers for the measurement of radon indoors, in soil, and in water with the most simple and universally known contamination monitor: the pancake Geiger-Muller.

Ref.

[1] Von Philipsborne H.: *Spot measurements of radionuclides in air, water and solids with a single instrument*. Proc. IRPA Regional Symposium. Radiation Protection in Neighbouring Countries of Central Europe, Prague, 8-12 September, pp611-614

A4

SELECTED STATISTICAL PROBLEMS IN SPATIAL EVALUATION OF Rn RELATED VARIABLES

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As a result of a quite complex series of interacting physical processes the quantity "indoor Rn concentration" has analytical and statistical properties, which pose problems to spatial evaluation, estimation and prediction, and ultimately to mapping.

Rn generation and transport is controlled by geology, and therefore spatially variable. Being subject to meteorology, Rn transport in soil is temporally variable. Accumulation in buildings is determined by house properties and living habits. The result is a spatio-temporal variability on many scales, which leads to uncertainties of various types if spatial quantities, shall be estimated, like expectation on a point or over an area.

In this contribution, we want to give an overview on conceptual and statistical problems encountered in these tasks. We start with discussing the concept of "target variable", i.e. the problem of properly defining of the physical quantity, which is to be assessed, depending of the purpose of the effort. This is related to the notion of "support", that is the spatio-temporal unit, or intervals, to which estimates refer, and from which inference is made. Since we are interested in spatial assessment, we discuss how to eliminate temporal dependence. Then we proceed to the question how to produce a spatial estimate of the target variable over a given spatial estimation unit (point, grid cell, geological or administrative unit): methods addressed are geostatistics (kriging) and lognormal modelling, possibly enhanced by Bayesian reasoning.

Any estimate has an associated uncertainty, representing the probability distribution of the deviation of estimate and true value. We present a typology of uncertainties, discuss their physical sources and mathematical properties, and suggest ways how to identify them. Given the rather complex way from a measurement to a possibly highly aggregated estimated target variable, there are still unresolved issues here. A notably tricky issue is the definition, delineation and quantification of "Radon-prone zones".

Currently under discussion as input to a European geogenic Rn map is a "Radon index", derived from different physical input variables (indoor Rn, soil gas, geology, geochemistry, eU,…) based on country-wise incomplete datasets. Mathematically, this Radon index should be a well-ordered categorical variable, ultimately related to a probability to exceed a threshold. We address the problem of classification and the uncertainties related therewith.

A5

DEVELOPMENT OF AN INDOOR THORON MODEL

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Increased concentrations of thoron and its decay products were recently found in traditional Chinese clay buildings. Conditions, which cause such concentrations, were examined in a room, which has been rebuilt to scale at Helmholtz Zentrum Muenchen, and in the laboratory. It could be shown that increased thoron exhalation rates can also occur with clay of average thorium content. At an increase of the air exchange rate, a strong decrease of the decay product inventory but an increase of the inventory of the thoron itself could be observed. Furthermore, the influence of the aerosol concentration on the unattached fraction of the thoron decay products was determined. Deposition to the walls, floor, and ceiling was investigated and deposition velocities of the decay products were measured. The obtained information was used to set up an indoor compartmental model of thoron and its decay products. With this model, indoor concentrations can be predicted in dependence on ventilation rate, exhalation rate of the building material, and aerosol particle concentration.

A6

APPLICATION OF NUMERICAL MODELS FOR THE RELIABLE DESIGN OF RADON PREVENTIVE AND REMEDIAL MEASURES

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The risk of radon penetration from soils into buildings is in several countries (Czech Republic, Sweden, Germany, etc.) expressed by the radon index of the building site. Its determination is based on the assessment of the soil permeability and soil gas radon concentration. Both parameters are measured directly on the particular building site at a depth of approximately 0,8 m below the ground level and their values are used for the design of protective measures against radon from the soil. It is usually assumed that radon concentration under the house corresponds to the concentration measured at the depth of 0,8 m below the uncovered ground level. However, radon concentrations measured in the sub-floor layer under completed houses revealed that this assumption is mostly not true.

Changes of soil gas radon concentration caused by the building itself were studied by numerical modelling with the help of the computer program Radon2D [1]. This program solves the well-known equation describing two dimensional steady state radon transport in a porous medium caused by diffusion and convection. Several soil profiles and three positions of houses in each soil profile with respect to the ground level were considered during the modelling.

Results of numerical simulation showed that under the floor of the houses resting on the ground level soil gas radon concentration can be up to 3,4 times higher compared to the concentration measured at the depth 0,8 m. Even higher increase was predicted for houses with the floor embedded 2 m below the ground level. In this case the sub-floor concentrations increased up to 9,3 times. In general, the smallest differences were observed for houses with floors raised 0,6 m above the ground level. Concentrations calculated in the sub-floor layer of such houses were in maximum 2,6 times higher compared to the values at the depth 0,8 m. In particular cases the sub-floor radon concentrations are influenced mainly by arrangement of soil layers of different permeability and radon production rate and by house parameters, such as airtightness of floors, underpressure within the house or presence of highly permeable drainage layers made of coarse gravel under the house.

It can be concluded that soil gas radon concentrations under the houses can significantly differ from concentrations measured on the building site and used for the assessment of radon risk categories. The highest differences were predicted for soils with highly permeable upper layers.

We have found out that numerical modelling is a powerful tool applicable for the prediction and evaluation of such differences. Model calculations can thus contribute to the improvement of the design of radon protective measures that could become more precise and reliable.

Ref.

[1] Jiránek M., Svoboda Z. : Numerical modelling as a tool for optimisation of sub-slab depressurisation systems design; *Building and Environment 42 (2007),* pp. 1994-2003.

A7

RADON AND ITS DECAY PRODUCTS DYNAMICS INSIDE THE ACCUMULATIVE CHAMBER

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The calculations of radon and its decay products accumulation dynamics inside a chamber designed for measurements of radon flux density from the soil surface were carried out in the present work. Dynamics of alpha-, beta-particles and gamma rays output count rate under decay of accumulated radionuclide nuclei were calculated based on the accumulated activity. Ionisation rate inside the accumulative chamber due to radiations of different types was also estimated. Rate of ion formation inside the accumulative chamber due to radiation of different types was also estimated. Based on these calculations:

a) the availability of different types of detectors for measurements of the radon flux density from the Earth surface was estimated;
b) the choice of the measured parameter and detector subject to its registration efficiency, signal-to-noise ratio was supported. The optimum exposure time of the accumulative chamber depending on a detector type and measurement conditions was determined. Dynamic equations of the studied radiation characteristics, their solutions and the analysis of obtained results are presented in the work.

A8

SOIL-GAS, GROUNDWATER AND INDOOR RADON LEVELS VARIATIONS IN THE GRANITIC TERRAIN, TUSHAM RING COMPLEX, HARYANA, INDIA

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This paper presents the results of investigations of radon levels in the soil-gas, groundwater and indoor air in dwellings of the high heat producing (HHP)-granitic region of Tusham ring complex, Bhiwani District, Haryana. Radon release from soil and groundwater was found to be comparatively higher than the values observed in the nearby non-HHP/non-granitic regions of Haryana & Punjab. The soil-gas and the groundwater radon concentration of HHP region of Tusham ring complex varies from 42.8±0.7 to 71.5±3.2 kBq m^{-3} with an average value of 61 kBq m^{-3}, and from 17.4±1.3 to 49.7±1.7 Bq l^{-1} with an average of 26.2 Bq l^{-1} respectively, whereas in non-granitic/non-HHP regions the average value of 31.5 kBq m^{-3} (range 16.3±0.8–44.1±1.8) and that of 7.9 Bql^{-1} (range 4.7±0.7–14.0±1.2), respectively have been observed. Indoor radon concentration in around 155 traditional dwellings in a wide range of villages situated in this region has also been measured using the nuclear track etch detectors(LR-115) during two years. Indoor radon levels in these dwellings have been found to vary from 109 ± 80 to 1006 ± 55 Bq m^{-3} whereas the annual average radon values vary from 60 ±37 to 235 ±55 Bq m^{-3} in the dwellings of the villages studied in a non-HHP region of Amritsar District, Punjab. A positive correlation has been observed between the soil-gas and indoor radon levels particularly in the periphery of the exposed HHP rock formations, which may likely be the result of the influence of imbedded and exposed high heat producing (HHP) granitic rocks and thus the active-soil formations. Even a good correlation (R^2=0.6) between soil-gas concentration and radon exhalation rate and even a slightly positive correlation between soil-gas radon concentration-exhalation rate and indoor radon level has been observed, indicating the presence of radon in collected soil/rock samples and the surface air due to the distribution of uranium and radon in soil & rock samples of the HHP Tusham region.

Certain specific locations within the periphery of well exposed HHP-granite rich formations clearly indicate the variation of soil-gas radon concentration with petrography of the region, contributing to the high indoor radon levels in these specific locations only. Variation of the radon exhalation rate, effective radium content from the soil/rock of the region with the gamma dose rate will also be discussed.

A9

RADON IN POTABLE WATER OF LUXEMBOURG

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The presence of elevated concentrations of radon in water is a potential health risk when the water is used in households, mainly because of the increase of radon concentration in indoor air (Erlandson et al. 2001; Zalewski et al. 2001).

In 2007, two measurement campaigns were carried out to estimate chemical parameters in all potable water sources used in the territory of Luxembourg. As part of this programme, the concentrations of natural radioactive isotopes in these drinking waters were determined.

We present here the results of radon activity. The LSC technique was used. For quality assurance of our results we made three replicates from each collected water sample. This methodology was used because it is more accurate than other possible methods of radon measurement, and its limit of detection is sufficiently low, i. e., 700 Bq m^{-3}.

The correlation between radon and radium levels was estimated, together with the dependence of radon levels on geology. The results are interpreted and compared with those obtained previously.

Seasonal variation of radon concentration was observed by monitoring five of the water sources monthly throughout the year.

A10

RADON IN DRINKING WATER IN SWEDEN - MUNICIPAL WATER SUPPLY VERSUS PRIVATE WATER SUPPLY

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Radon (^{222}Rn) in drinking water is principally a problem for private well owners. About 15 % of the Swedish households are not connected to a public water supply but have either a dug or a drilled well. Elevated radon concentrations are often encountered in water coming from wells drilled in bedrocks, containing medium to high uranium content. Various studies on different scales have been performed to study the occurrence of ^{222}Rn in private wells. The very first nation wide survey of radon in drinking water started in the late 70's. Kulich et al. (1988) studied 500 drilled wells which were randomly selected and the median radon concentration observed was about 80 Bq/l and the maximum radon concentration was 8855 Bq/l. A second and more recent mapping of the occurrence of radioactive nuclides including ^{222}Rn was performed during 2001-2006 (Ek et al., 2008). In this collaboration study between the Swedish Radiation Safety Authority and the Geological Survey of Sweden, a total of 700 drilled wells were investigated throughout the country and stratified sampling was used. About 100 wells were sampled in uranium-rich geological media while the remaining 600 wells were randomly sampled outside risk regions. The median radon concentration was about 200 Bq/l in both cases but the maximum radon concentration registered were 9800 Bq/l outside risk regions and 22400 Bq/l in risk regions respectively. The study also revealed that 8% of the investigated wells have radon concentration exceeding 1000 Bq/l, which is the recommendation, set by the National Board of Health and Welfare. Water in only 33% of the private wells would have been qualified as safe for consumption if the legally binding limit of less than 100 Bq/l that is set for municipal water was to be applied. Radiation dose due to ingestion of ^{222}Rn was found to exceed 0,1 mSv/year in about 22% of the wells. This study also revealed that long-lived decay products of ^{222}Rn, namely lead-210 and polonium-210 might also contribute to a significant dose. Analysis and remediation of high concentrations of ^{222}Rn in drinking water coming from private wells is the responsibility of the owner. The majority of the Swedish households (85%) are connected to public waterworks. About 50% of the water works use surface water and 50% comes from groundwater produced by artificial infiltration in soil aquifers. The quality of water regarding the content of ^{222}Rn is regulated by the National Food Administration. The legally-binding limit is 100 Bq/l and remediation measures are necessitated if that limit is exceeded. Water containing 1000 Bq/l cannot be used for consumption. Radon concentration in water coming from a municipal water supply is in general low, with a median radon concentration of 10 Bq/l, except in few cases where groundwater is used (Falk et al, 2003, Kulich et al., 1988). For a majority of the Swedish population, radon is not a problem in drinking water.

Ref.

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A11

INVERSION OF THE JACOBI-PORSTENDÖRFER MODEL FOR DECAY PRODUCTS OF RADON IN AIR OF ROOMS

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The Jacobi-Porstendörfer room model distinguishes concentrations of free and attached decay products of radon (d.p.Rn) in air and introduces (besides of the ventilation coefficient k) the attachment rate X, deposition rates to surfaces for free q_f and attached q_a of d.p.Rn and the recoiled fraction R to describe the intrinsic dynamics of d.p.Rn in air. Here a solution is given of the algebraic and statistical inversion of the set of six (resp. nine) recurrent equations for the six concentrations of free and attached d.p.Rn in air (resp. plus surface activities of d.p.Rn). Unfortunately the algebraic inversion is exactly possible only for correctly calculated results of measuring. For real measuring values several sets of the five parameters k, X, R, q_f, q_a results (with some values outside of real requirements) between which objective criteria have to decide about acceptable results.

For statistical solution of this problem a sophisticated Bayesian approach (better than the common linear programming) is used. Results of both approaches are presented.

A12

FIRST RESULTS OF MEASUREMENT OF EQUILIBRIUM FACTOR F AND UNATTACHED FRACTION f_p OF RADON PROGENY IN CZECH DWELLINGS

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The unattached fraction of radon decay product clusters f_p and equilibrium factor F are dose relevant parameters in all dosimetric approaches to dose calculation. The results of sensitivity analysis applied to the classical Jacobi–Porstendörfer room model describing generally dynamics of both unattached and attached short-lived radon progeny in a room indicated the air exchange rate, plate-out and attachment rate of unattached progeny as key quantities and f_p and equilibrium factor F as the most strongly affecting the behaviour in a room.

In the past three years weekly continuous measurements of unattached and attached activity of each radon progeny and air exchange rate were carried out in thirty occupied typical Czech family houses.

The main goal was to compare directly measured values of f_p and F with those values calculated via the room model on the basis of estimated key quantities for living conditions and implicitly to improve dose calculations for members of public.

Used approaches to estimation the key quantities, QA for used measuring devices based on the NRPI Radon Chamber Facility and the results of measured f_p and F with impact to dose calculations are reported.

A13

GEOCHEMICAL CASE STUDY OF SOIL AND SEDIMENT SAMPLES FROM ASKOLA, FINLAND - ASSESMENT OF RADON EMISSION

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In order to define the naturally-occurring radioactive materials that are source of radon in natural environments, a comprehensive analytical (geochemical, physical and chemical) methodology was employed to study soil and sediment samples from an esker formation close to a uranium mineralization in Askola (SE Finland). Techniques such as gamma-spectrometry, emanation measurements, sequential chemical extraction, scanning electron microscopy (SEM), electron microprobe analyses (EMPA) and inductively-coupled plasma mass spectrometry (ICP-MS) were used to determine the potential source of radon.

Samples are representing podsolic soil profile formed on esker sediments deposited at various flow energies. In Askola samples the activity concentration of ^{238}U shows very weak increase versus depth, whereas ^{226}Ra and ^{228}Ra increase significantly with depth. Secular equilibrium between ^{238}U and ^{226}Ra occurred only in the deepest sample. In upper soil horizons A and B higher uranium than radium concentrations were measured, whereas at the deeper horizons radium is higher than uranium. Highest disequilibrium occurred in the samples of weakly sorted sandy till and well sorted coarse grained sand, whereas $^{226}Ra/^{238}U$ is 1.6. In ^{232}Th decay chain significant disequilibrium occurred between ^{232}Th and ^{228}Ra except in the deepest sample. The highest disequilibrium was measured in the well sorted sandy sample ($^{226}Ra/^{238}U = 0.4$). Radon production and emanation factor varying between 0.11-0.36 Bq/(kg h) and 0.28-0.41, respectively. Clayey sample has the highest radon production and emanation factor (0.36 and 0.41, respectively) of all the samples from Askola. This sample has one of the two highest ^{226}Ra content (116 Bq/kg), as well. Sandy sample has the lowest emanation factor (0.28). The lowest radon production was measured in top soil sample.

Uraninite, thorite, thorianite, monazite, xenotime, and zircons were identified in the samples as the main sources of uranium, thorium and radium. These minerals were highly weathered in the upper two soil horizons and mainly fresh in the deeper ones. By electron microprobe analyses in-grain redistribution of uranium and thorium were studied. On one hand leaching of uranium and light rare earth elements, on the other rather fast re-precipitation of thorium was detected.

A14

SIMULTANEOUS MEASURING OF LOW ^{222}RN AND HIGH ^{220}Rn EXHALATION RATES OF SOIL SAMPLES USING RAD7

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There is a natural, mostly ^{232}Th-caused, relatively large-sized radioactive anomaly at Nagy-Kopasz hill situated west to Budapest (Hungary) [1]. On this area at Szarvas valley (south side of Nagy-Kopasz hill) a local radioactive anomaly can be observed on total gamma intensity maps. Using a portable gamma-dose power meter (Thermo FH 40G-L10 and FHZ612-10), we located this site in the field and studied in details the area of approx. 10 m^2. Based on high radioactivity (1-2 μSv/h on the ground), a type of brownish yellow clayey soil can be distinguished and was collected for laboratory investigation.

Wet-sieved grain size fractions of the soil sample was examined by scanning electron microscopy (Amray 1830 I/T6) and X-ray spectroscopy (EDAX PV 9800). We found that ^{232}Th is in the smallest grain size fraction in a mineral identified as cheralit [$(Ca,Th)PO_4$]. The studied bulk soil sample contains more than 150 ppm of ^{232}Th (measured with gamma-ray spectrometry using GC1520-7500SL HPGe detector). We determined the ^{222}Rn and ^{220}Rn exhalation rates [2] of the bulk sample and its grain size fractions by accumulation technique. The samples were placed into accumulation chambers and were kept for three weeks to set the equilibrium between ^{220}Rn and ^{224}Ra and between ^{222}Rn and ^{226}Ra. Then we used RAD7 radon detector to determine the ^{222}Rn and ^{220}Rn concentrations inside accumulation chambers. However, the RAD7 detector provided incorrect values of ^{222}Rn concentrations because of an interference with a daughter of ^{220}Rn.

RAD7 detector determines the radon and thoron concentrations by alpha-counts of ^{218}Po and ^{216}Po isotopes [3]. Also, ^{212}Bi is in the thoron's decay chain. It emits 6.05 MeV alpha-particles with 35.94% probability, whereas the ^{218}Po alpha's energy is 6.00 MeV [4]. The counts of ^{218}Po and ^{212}Bi cannot be discriminated from each other. In the RAD7 detector a correction factor (64.06% / 35.94% ≈ 2) is applied by the vendor, which is only an approximate value [3]. It provides only a brief radon concentration value at high concentrations of thoron. We solved the problem by calculating and testing a new correction factor.

Due to the new correction factor, the ^{222}Rn and ^{220}Rn exhalation rates of the studied samples were determined simultaneously. A clear correlation between the exhalation rates of the two isotopes was detected in the sieved grain size fractions of the collected soil of Nagy-Kopasz hill. We observed that the wet-sieving results in a loss of ^{222}Rn and ^{220}Rn exhalation.

Ref.

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A15

RADON MITIGATION STUDY CLOSE TO FORMER URANIUM MINING (MECSEK MTS, SW-HUNGARY)

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At Kővágószőlős (Mecsek Mts., S-Hungary), where the Hungarian uranium mining lasted for 40 years, most of the dwelling houses, located close to the mine-tunnel, show a yearly average of indoor radon activity concentration higher than the EU recommendation for existing buildings (400 Bq/m^3). Our goal is to define the source of the high indoor radon concentration, as well as to perform the radon mitigation in one of these houses.

The chosen house is located directly above the mine-tunnel by 60 meters. It is about one hundred years old, built of brick and stone, two floored family house with basement; it represents an average one of the houses around the area.

Four different types of indoor radon concentration measurements were done and laboratory measurements of ground soil and building material samples have been analyzed. Our study included long and short term, as well as active and passive indoor radon concentration measurements, radon exhalation rate and radium content measurements.

Basing on our detailed evaluation of indoor radon concentration it is far above the recommended level. Evaluation and comparison of the results, obtained on building material and soil sample, indicates that the radon exhalation rate of the building material is negligible compared to the exhalation from soil, the radium content of the soil is twice of the world average. Accordingly, the source of the high indoor radon concentration should be in the soil.

The radon mitigation was performed by a commercially available special sealer material. The product used is a surface gas drainage system, which behaves like the gravel layer under the house. It collects the emitted radon gas from the soil transmitting it outdoors through a pipe. This is a passive system, which needs no artificial ventilation. The radon mitigation was performed in the basement and in the dining room using the material described above. The average radon concentration before the action was 1479Bq/m^3 for a period of 1 month, but after the mitigation it decreased down to 344 Bq/m^3 as another monthly average, which is below the recommended level in Hungary.

A16

LONG TERM MEASUREMENTS OF RADON EXHALATION RATE FROM SOIL

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The process of radon exhalation from soil is not simple and depends on many factors, not only on those regarding soil characteristics (radium Ra-226 content, density, porosity, permeability) but indirectly on meteorological conditions as well. In particular, soil temperature and humidity influence strongly exhalation rate and they are modified by weather conditions.

In the years 2003 – 2006 the systematic measurements of radon exhalation rate from soil were performed at the special site (Radon Study Field) located at the Institute of Nuclear Physics PAN, Kraków. The continuous registration of meteorological parameters was also carried out on the spot by means of the Weather Monitor II (DAVIS production). During the first two years radon exhalation rate was determined 3 – 6 times a week using the AlphaGUARD radon monitor together with a special accumulation container. In order to find relationship between meteorological conditions and radon exhalation rate from soil, the automatic device was applied which made it possible to perform 4 measurements a day. It enabled to investigate diurnal and seasonal variability of radon exhalation rate.

The analysis of obtained results showed that the most clear correlation exists between air temperature and radon exhalation rate. The similar conclusion was drawn as regards soil humidity and soil temperature.

The attempts to find correlations between individual weather parameter (e.g. air pressure or wind speed) and radon exhalation rate failed. Since meteorological parameters influence each other, it seems that more complex analysis is needed to search for correlations. The preliminary results of multi-parameter analysis are presented.

A17

RATIONALE, HISTORY AND PROJECTED FUTURE OF EUROPEAN RADON MAPS, AS PART OF THE EUROPEAN NATURAL RADIATION ATLAS

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The Joint Research Centre (JRC) of the European Commission has a legal mandate under the Euratom Treaty to collect, evaluate and disseminate information related to environmental radioactivity within the European Union. This mission also covers studies on natural radiation, be it background or anthropogenically enhanced.

In the context of the preparation of the European Natural Radiation Atlas, it was decided to start the project with a feasibility study on the most challenging issue, the mapping of indoor radon. During the *8th International Workshop on the Geological Aspects of Radon Risk Mapping* in Prague in September 2006, participants agreed to contribute data to a European indoor radon map. It is based on cells of size 10 km × 10 km, aligned to a common European coordinate grid and filled by the project partners by aggregating individual measurements.

The purpose of the map is to give a picture of the spatial distribution of indoor radon levels (and derived quantities) on a European scale. It is not intended to substitute or trespass on national efforts of surveying the radon situation; in particular, no local predictions can be inferred from it. On the contrary, the engagement of the JRC with respect to radon will encourage further work on the topic, increase awareness of radiation in the environment, and spread scientific and technical know-how.

The next step envisaged, that is in part parallel to the indoor radon map, is a geogenic radon map. The idea of the geogenic radon potential concerns, roughly, the part of the radon hazard which is generated by the geological and geophysical environment, without anthropogenic influences like construction styles and life habits; the latter may enhance or reduce this hazard.

As further stages of the atlas of natural radiation, we are considering radon exposure maps, outdoors radon and radon flux maps, geochemical maps, and maps of other sources, and exposure pathways of naturally occurring ionizing radiation.

A18

STATUS OF THE EUROPEAN INDOOR RADON MAP

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In 2005, the Joint Research Centre (JRC) published a survey [1] of Rn monitoring efforts made in European countries; it showed a colourful, but disparate mosaic of approaches with hardly comparable results. As a consequence of differences in policy and legislation between countries, different quantities are assessed, and these are mapped in a rather wide variety of different methods, tailored to serve individual needs and conditions.

As part of its mission to collect information, make results comparable and present them on a European scale, the JRC launched the idea of European Rn maps, both indoor and geogenic, given the high radiological importance of exposure to Rn. At the seminal conference in Prague, September 2006, the participants agreed, as a first step, on an indoor Rn map, based on individual measurements in ground floors of buildings. The national participants aggregate their data into cells of size 10 * 10 km², which are aligned to a common European metric coordinate grid. The cell data are sent to the JRC, where they are collected and mapped. Given the size and complications of the endeavour and differences in data coverage, processing and representation between the countries, the map is far from complete.

We present the current status of the map, based on contributions from participating countries. We draw some preliminary conclusions, and discuss certain statistical procedures which we have applied for – so far only roughly, given the fragmentary state – testing the plausibility of data and compatibility between participants.

We also discuss some remaining issues, such as the minimum number of observations needed per grid cell to make meaningful estimates, and how to represent areas with very few data points, or even where no data can be expected because of restricted access. Seasonal variations in the data should also be compensated for. Finally, there are countries that have data available only at the local level or in their national projection systems, and these should be aggregated and converted into the common European grid.

Ref.

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A19

RADON POTENTIAL MAP OF PEST COUNTY, HUNGARY

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^{222}Rn and its effect to the human organism got into the centre of attention nowadays. This radioactive gas, which can be found in the uranium-238 decay chain, in the houses accounts for about 9% of deaths from lung cancer and about 2% of all deaths from cancer in Europe. It comes into the houses and other buildings from the natural decay of uranium in soils, rocks and building materials. Therefore, it is important to know the content of uranium and radium in soils.

Samples of a countywide soil survey (Soil Information and Monitoring System) of Pest County (Central Hungary) were examined to have experimental information of the potential radon risk. Our main aim is to determine the radon potential based on activity concentrations and radon exhalation rates for the sites of the areal survey.

The samples were collected at 43 localities from the surface level down to 60-120 cm in depth depending on the soil profiles. Generally, four soil samples were collected at each site point. The samples were selected to be representative for that soil found in the profile. We measured the specific activity of uranium, radium, thorium and potassium using HPGe gamma-spectroscopy technique. Radon exhalation of the samples was also examined by use of closed radon accumulation chamber coupled with RAD7 radon monitor detector. The exhalation coefficients were calculated that show diffusion ability properties of the grains and depend strongly on the genetic level and type of the soil sample studied. We determined activity and exhalation properties of several soil types and then we constructed maps and compared these to those of soil types, as well as isogamma and geology maps available from the studied area.

A20

NATURAL TERRESTRIAL DOSE-RATE AND INDOOR RADON MAPPING IN ISRAEL

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The exposed rock sequence in Israel consists mainly of sedimentary rocks – limestones, dolomites, chalks and sandstones – ranging in age from Paleozoic up to recent soils. Precambrian igneous (granites) and metamorphic (schists and gneisses) rocks are found only in the most southern part of Israel, in the vicinity of the Gulf of Elat.

A map of the natural terrestrial dose-rate in Israel was prepared, based on an airborne radiometric survey and complementary ground measurements. The airborne system included NaI crystals (40 liters) measuring terrestrial gamma radiation and a 0.4 liter crystal which measured the contributions of cosmic radiation and radon in the air. Four channels were measured – thorium (2.62 MeV resulting from ^{81}Tl), uranium (1.76 MeV; ^{214}Bi); potassium (1.46 MeV; ^{40}K) and total count (0.3-3.0 MeV). Flight altitude was 400 m above ground, and the flight paths were perpendicular to the dominating geological structures, which are trending from SW to NE. The flight lines were spaced 1 km apart and every 5 km a right angled control path was carried out. The ground measurements, taken at 1 m above the surface, were made by an Automess Scintomat device. The average dose-rate for the entire area of Israel is 0.28 mGy/year; the dose-rate for some 20% of the area ranges between 0.47 (95 percentile) and 5.1 mGy/year (maximum). The most high natural background radiation terrains (1-5.1 mGy/year) cover some 10% of the area, in which mainly the rocks of the *Mount Scopus Group* are exposed. This Senonian-Paleocene-aged group is characterized by phosphorite layers with appreciable amounts (90-150 ppm) of uranium. Thus, the main contribution of radiation in these terrains is that of the uranium series. Elevated radiation levels in other areas are due to higher concentrations of thorium and potassium in rich soils and outcrops of young basalts.

A radon survey in Israeli ground-level dwellings, consisting of nearly 2000 measurements was completed. The national average radon concentration was found to be 47 Bq/m^3. A significant correlation was found between geological conditions and indoor radon concetrations: houses built on the *Mount Scopus Group* rocks (high phosphate) have an average radon concentration (80 Bq/m^3), almost twice as high as houses built on other rock units (43 Bq/m^3). This correlation can be used as a planing and developing tool in inhabited areas in Israel and adjacent countries. The rocks which compose the *Mount Scopus Group* are widely spread all over the eastern and southern Mediterranean region, forming the Thetian Phosphorite Belt. Although in most cases the outcrops of uranium-rich phosphorites are located in desert areas, some heavily populated cities are located in these regions, i.e East Jerusalem, Arad (in Israel) and Amman (in Jordan).

A21

NATURAL RADIONUCLIDES IN WATERS FROM UPPER SILESIA, POLAND. DOSES AND COMPLIANCE WITH REGULATIONS.

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In the framework of a European Union Project ("WATERNORM") a large number of bottled mineral waters were bought at supermarkets and analysed mainly for Ra-226 and Ra-228. Those waters are sold all over Poland in very large quantities and so they can be assumed to be a representative source for the dose to the Polish population due to mineral water consumption. The results will be discussed on the basis of European Union legislation.

Samples were also taken in Upper Silesia and adjacent areas from a large number of spas, but also from water sources from wells and springs, which are widely used by the local population. An initial overview will be given on doses to be expected from consumption of these waters.

A22

ENVIRONMENTAL AND RADON MEASUREMENTS IN THE UNDERGROUND WORKPLACES IN CZECH REPUBLIC

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Most of radon and other environmental measurements were carried out in connection with research focused on improvement of radon dose assessment in the underground workplaces in the Czech Republic. The following methods were very useful for the detection of radon sources: air flow measurement; continual and short volume activity of radon and its progeny measurement; volume activity of thoron measurement; mapping of radon level in all workplace areas including horizontal and vertical gradient; radon in water measurement; integral radon monitor RAMARN testing, etc. The measurements were realized in public open caves, wine cellars, tunnels and speleothrapy areas.

In conjunction with EER monitoring in caves the studies of radiogenic characteristics of caves clastogene sediments (allogene and speleogene clays, fluvial sediments), carbonate sediments (limestone, dolomite) and other rock formations present in the Czech Massif (Devon period) and Western Carpathian Mountains (Jura period) were conducted. As compared to the clastogene cave sediments the radioactivity of carbonate sediments is very low.

The relation between EER and the radioactivity of clastogene sediments was studied in individual caves (in situ surface emission of radon). Over 150 samples of cave sediments were collected, in which mass activities of radionuclides present were determined, using laboratory semiconductor gamma spectrometric analysis (Marinelli geometry). Spectrometric analysis of the sediments enabled monitoring of disturbance in secular radioactive equilibrium in the given geochemical systems, through evaluation of $^{238}U/^{226}Ra$ or $^{228}Th/^{224}Ra$ proportion. Chemical processes causing the imbalance of the secular radioactive equilibrium, depicting the geochemical dynamics of the studied geological rock group (oxidation and reducing reactions, dissolution, crystallization, partial melting, absorption, phase changes (fluid – gas), are worth consideration in the case of studied carbonate rocks, mostly dissolution and re-crystallization.

The knowledge of mass activities for ^{226}Ra, ^{40}K and ^{232}Th in the individual collected samples could be the important indicator for judging of categorizing the above mentioned samples to the appropriate rock groups from the genesis point of view. The $^{208}Tl/^{226}Ra$ ratio was monitored. Typical values for such ratio for carbonate rocks (including amphibolite and erlan) varied between 0.2 -0.5, while for clastogene sediments and crystalline limestone the typical values of this ratio were in the range 1.4 – 1.6. In three cases (among the analyzed samples) the isotope ^{137}Cs was found, suggesting a surface source of the sediments present.

The conclusions from the results of these measurements were implemented in the new methodology for radon dose assessment.

A23

BACKGROUND OUTDOOR RADON LEVELS IN SLOVENIA

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Radon (^{222}Rn) activity concentration was measured in outdoor air by two three-month exposures of nuclear track detectors in the periods March–June and July–September, 2005. Sixty sampling points were uniformly distributed over the territory of Slovenia (20 thousand km^2), in an irregular grid with mostly 20 km × 20 km squares. Nuclear track detectors based on CR-39 foil (Radonlab, Norway) and Makrofol E (KfK, Germany) were mounted in a diffusion chamber at the height of 1.5 m above ground.

The overall geometric mean of 11.8 Bq m^{-3}, with the standard deviation of 2.2, was obtained. The country was divided into eight natural units; the lowest average values were observed in the Subpanonic region in the north-east (8.6 Bq m^{-3}), in the Ljubljana basin in the central part (9.0 Bq m^{-3}) and in the Alpine region in the north (9.1 Bq m^{-3}). The highest were on the Low Dinarides plateau in the south-east (16.8 Bq m^{-3}) and on the High Dinarides plateau in the south-west (23.6 Bq m^{-3}). The figures do not represent annual averages. These are expected to be higher because of long wintertime temperature inversions in certain regions.

The map of outdoor radon levels in Slovenia was elaborated. It can be concluded that the regions with low and high outdoors radon activity concentrations coincide quite well with the regions of corresponding levels of radon potential in soil gas.

A24

RADON CONCENTRATION IN ĐUROVIĆA CAVE (ČILIPI, CROATIA)

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Đurovića cave is located near the control tower of the Airport Dubrovnik. In last ten years, there were several geomorphological, meteorological, archaeological, palaeontological and biospeleological research campaigns ordered by the airport management who is interested in its use for tourist purposes [1]. The cave is located on a small karst plateau and was formed in the Upper Cretaceous limestone and breccia beds along the fissures which controlled the passage directions as well as inclination. It is a 156 m long simple cave consisting of main passage and chamber called "Dubrovačka Republika" (DR). The depth of the cave is 25 m (129 m above sea level and 49 m above the Konavosko polje level). In geomorphological sense, the youngest part of the cave is the DR chamber formed at the intersection of older and younger (neotectonic) fissure systems. Cave clay, rock debris and large blocks predominate among the cave sediments. The cave itself is also very rich in all kinds of speleothems which is very suitable for tourist use [1]. Because of these characteristics and in respect with similar karstic tourist caves from literature [2] the elevated radon level is expected.

Integrated radon measurements by means of track etch detectors (two LR-115 II films per detector cup) were started from October 2008 and are still going on in order to determine the seasonal variability. First set of 15 detectors were exposed for 55 days; ten detectors were placed along main passage while 5 detectors were placed at DR chamber. The four detectors were flooded because the dripping water is abundant in wet season. The obtained radon concentrations were in range from 6.3 to 11.3 kBq m^{-3} with average value of 9.0 kBq m^{-3} and standard deviation of 1.6 kBq m^{-3}. There was no difference between radon concentrations in main passage and DR chamber. The applied radon measuring method with two LR-115 II films enable estimation of equilibrium factor between radon and its short-lived progenies [3] and the average value of 0.395 with standard deviation of 0.207 were obtained. These preliminary data, according to dose conversion factors published in ICRP Publication 65 [4] (radon exposure of 1 Bq h m^{-3} is equivalent to the effective dose of $3.108 \cdot 10^{-6}$ mSv) give dose rate in Đurovića cave of 0.028 mSv/h. In order to preserve annual effective dose of workers in cave (future tourist guide) below action level for workplaces (10 mSv) he/she should not be more than 357.5 hours per year in cave.

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A25

SEASONAL VARIATION OF RADON IN CAVE

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The measurements of radon concentration have been performed in the Bozkov dolomite cave since 2002. Radon concentration was measured in two ways: continuous measurement using Radim3 monitor in 30-minute intervals and 6-month average by LR115 SSNTD in the diffusion chamber placed at 8 points along the cave tour route.

The radon concentration shows diurnal, seasonal, and yearly variations. The maximum concentration in the caves, in contrast to the dwellings, is in the summer time. At the same time high variability of radon concentration occurs. The statistical analysis of long time series of radon concentration was performed; the meteorological data were taken into account.

This type of measurement is interesting from the cave environment behavior study point of view.

Short term measurement (1 month) of radon and radon progeny concentration is discussed also.

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A26

RECENT RADON EXPERIENCE IN BULGARIA-FROM RETROSPECTIVE MEASUREMENTS TO MITIGATION

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An overview of ongoing radon research in University of Sofia, Bulgaria is presented. At present we are focused on: 1) study and implementation of the polycarbonate method for measuring ^{222}Rn in air, water and soil-gas, 2) surveys in radon risk areas in the country, 3) mitigation measures in dwellings with high radon.

The method based on high radon absorption ability of some polycarbonates was first proposed in 1999 [1] and has extensively been studied since that time. On its basis a method for retrospective ^{222}Rn measurements by home stored CDs/DVDs has been proposed [2], studied [3] and applied [4]. The design of the laboratory equipment and procedures for making retrospective measurements is described and the performance of the method is outlined. As any home stored CD/DVD appears to be a sufficiently precise "radon witness", the need and possibility for progress in the following directions is discussed: 1) collection and analysis of CDs/DVDs from houses of cases with lung cancer, 2) radon mapping based on retrospective measurements.

Till now radon surveys in Bulgaria don't cover the whole country and are concentrated mainly in risk areas. The results from years long follow-up in regions affected by former uranium mining and milling activities and in the town of Rakovski are presented. In Rakovski significant increase of lung cancer incidence is observed that can be explained by the increased ^{222}Rn concentrations. This town is a primary target for eventual case-control study in the future.

In Bulgaria the radon mitigation by active soil depressurization systems has commenced in the last years. Our "starting" experience in this field is shared on the example of two systems designed by us. An average radon reduction factor of about 50 was obtained using those systems.

In conclusion, there is a basis to enhance radon research, measurements and mitigation in our country. We feel that the progress will be more efficient in collaboration with the National Cancer Registry and the engineering staff engaged in mitigation, and with closer international collaboration, too.

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A27

APPLICATION OF RADIOMETRIC METHODS IN INVESTIGATIONS OF OUTBURSTS AND TREMORS IN POLISH HARD-COAL MINES

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In the 80's and 90's of twentieth century research activity on the application of radiometric methods supporting of outbursts' prediction in Lower Silesian mines has been undertaken. It was stimulated by an analogy to application of radon changes in water and soil gas before earthquakes. Therefore a hypothesis was proposed, that similar phenomena may occur in coal seams before and during outbursts of gas and coal. In Laboratory of Radiometry of the Central Mining Institute a technique of radon measurements in boreholes has been developed and applied for this purpose.

The analysis of results showed that changes of radon concentration in the starta was correlated with the level of an outburst hazard. Prior to the outburst a rapid decrease of radon concentration was often observed, while radon level grew quickly after the release of gas and coal. The best correlation between radon changes and outbursts' occurrence were obtained when radon changes were shown as a function of the heading advance. Results of these investigations were very promising therefore investigations of possible connections of radon changes and tremors have been started in coal and copper mines in Poland. In this case results and correlations weren't very clear and significant. In the meantime Lower Silesian collieries have been abandoned and no further investigations were possible.

Due to the increase of outburst hazard in some Upper Silesian coal mines we decided to continue investigations in these mines. We hope it would be possible to develop a "radon outburst's indicator" to support other methods of prediction of very dangerous geodynamic phenomena.

A28

A LIQUID SCINTILLATION SYSTEM FOR A RADON MONITORING NETWORK IN GEOPHYSICAL STUDIES

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Variation in radon concentration in groundwater is a possible earthquake precursor and can give valuable insight into the mechanical processes in the source volume of earthquakes. In order to get a reliable overview over these variations, before and after an earthquake, a network of continuously monitoring radon instruments in the seismic zone is needed. Lack of suitable low-cost instruments has been an obstacle in these studies. We present a promising candidate for this kind of work, AutoRadon, developed some years ago at the Science Institute University of Iceland, which has now been improved. The water to be monitored comes from deep geothermal boreholes and a slow stream is conducted through a silicon tube spiral around the open vial with scintillator The vial sits on the top of a 28 mm diameter phototube. Radon atoms diffuse reversibly through the wall of the tube and are absorbed in the scintillator. The compact microprocessorized electronic unit stores the results on an USB-memory, but can also send them once a day as an SMS message to a central computer. A network of 6 of these monitoring stations will be set up in a seismic zone in South Iceland.

A29

UPGRADE OF THE NIRS THORON CHAMBER - ITS PERFORMANCE AS THE RADIOACTIVE AEROSOL CHAMBER

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Since recent studies have shown that high thoron concentrations were observed in some areas, the dose from thoron progeny is significant in such areas. Additionally, developing an accurate measurement procedure for thoron and its progeny would be also beneficial for the radon and its progeny measurement due to interference from thoron and its progeny. To meet these challenges, we have been set up thoron chamber system in NIRS [1]. This study describes the performance of the chamber system as the radioactive aerosol chamber (**Figure**).

The thoron concentrations in the chamber are measured continuously every one hour using a RAD7 electrostatic collection method. For quality assurance of the continuously measured thoron concentrations, intermittent measurements are also acquired during the exposure test by means of grab sampling technique with a 300A Lucas cell and an AB-5 portable radiation monitor. The humidity of the air in the chamber is controlled by adjusting the volume ratio between the dry and humidified air in a mixing chamber before introduction into the chamber due to dependence of thoron concentration generated from the source on humidity. The unattached progeny is collected on a 400-mesh stainless-steel wire screen, while the progeny attached to aerosols is deposited on a glass fiber filter. After a 5-min sampling, alpha particles on the wire screen and filter are counted using a ZnS(Ag) scintillation detector. A condensation monodisperse aerosol generator is used; aerosol particles are generated by the evaporation-condensation method. Carnauba wax is used as the aerosol material in this study. Aerosol particle size distributions are continuously monitored by a scanning mobility particle sizer (SMPS) in combination with an ultrafine condensation particle counter and a long-type electrical classifier.

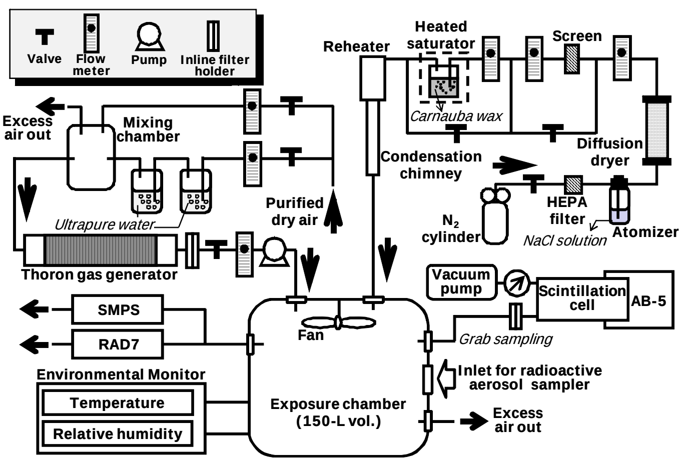

Figure. Schematic diagram of NIRS thoron chamber as radioactive aerosol chamber.

Ref.

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A30

MEASUREMENT OF CONTINUOUS SOIL GAS RADON VARIATIONS IN CONTEXT OF INDOOR RADON DIAGNOSIS APPLICATION

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In order to observe soil gas radon variations in close proximity of buildings, a specific continuous measurement technique was applied. The detection principle of the monitoring device is based on an airflow ionization chamber operating in a current mode. In addition, the unique sampling technical arrangements were designed and the take-off probe with a special end fitting, providing the defined continuous close circuit sampling, was applied. The special sampling procedure effectively eliminates the ambient atmosphere influence on a long-term soil-gas sampling (temperature and pressure fields effects). The close circuit arrangement with defined flow characteristics ensures a minimal impact on physical properties of a sampling space (draining effects, variable geometry factor etc.). Furthermore, the thoron (^{220}Rn) suppression unit was applied to eliminate the thoron additional signal by its radioactive decay in the retarding piping system, inserted in the close circuit. The comprehensive series of testing and calibration experiments were carried out in a laboratory environment. The experimental device can be used for different measurement procedures, concerning two major branches of applications. For the field applications, the continuous in-situ measurement of soil-gas radon concentration can be provided with regards to the study of earthquake prediction and investigation of ground water level fluctuations. For the indoor applications, the measurement system can be applied for continuous recording of radon concentration in samples taken from cracks and leakages in building constructions in contact with subsoil (the radon diagnosis method). The dynamical measuring range is sufficient for monitoring of indoor environment with high content of radon (caves, mines, underground workplaces, basements etc.). The system description including applied experimental conditions will be presented and some first results of in-situ measurements will be reported.

A31

PRACTICAL USEFULNESS OF RADON RISK MAPS AND DETAILED IN SITU CLASSIFICATION OF RADON RISK

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The presentation answers the frequent question about the practical usefulness, advantages and disadvantages of radon risk maps and detailed in situ classification of radon risk.

Czech Radon Programme derives benefit from radon maps in various scales - 1:500000, 1:200000 and 1:50000, as well as from the uniform method for direct detailed classification of radon risk. The reliability assessment of the practical usefulness is based on the direct comparison between the results obtained from detailed in situ classification of radon risk of building sites and the corresponding reading from the radon risk map. Altogether almost one thousand of detailed radon risk assessments, i.e. tens of thousands of soil-gas radon concentration measurements, were compared with expected radon risk categories in 5 radon risk map sheets in the scale 1:50000.

The new results more specify and correspond to the previous results from comparisons performed in 1992, 1995 and 2002. We can prepare quite consistent maps, which can be successfully used to direct the search of existing houses with higher indoor radon values. On the other hand, the risk of underestimation or overestimation in case of deriving the radon risk classification of a specific building site from the map seems to be too high to use the maps for direct assessment of specific sites. For new buildings, it is recommended to use detailed in situ measurements and classification.

A32

TWO SIGNIFICANT EXPERIENCES RELATED TO RADON IN A HIGH RISK AREA IN SPAIN

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Radon is a natural radioactive gas and it is currently accepted as the responsible for lung cancer in some cases [1]. One of the most important sources of indoor radon is the soil and the radium content of the soil is also a very important factor to take into account. The natural radiation map of Spain (MARNA) [2] classifies the country into three regions with different levels of natural gamma radiation. There are some areas in Spain with high levels of natural radiation. One of them is the province of Salamanca. Western part of this province presents a population of 20,000 inhabitants and 7% of the houses have an indoor radon concentration above 400 Bq m^{-3}. In this high risk area, the village of Villar de la Yegua is of special interest [3]. 75 % of the houses in this village have an indoor radon level above 400 Bq m^{-3} and the rest are above 1000 Bq m^{-3}. On the other hand, an old uranium mine site close to this village has been selected for the construction of an experimental pilot house. It is a two floor house located in a place with very high ^{226}Ra concentration in soil. Furthermore, radon in soil at 1m depth has an average level of 250 kBq m^{-3}.

We present in this work the characteristics of the experimental unit located in this high risk area and we describe the zone where one of the Spanish villages with the highest radon concentration is located. This is a very interesting place for further research on radon concentration indoors and it is a unique opportunity of testing radon monitors, radon passive detectors and remedial actions for the mitigation of radon in real conditions. It is common to carry out intercomparison exercises under laboratory conditions. Nonetheless it is not so common to develop these exercises in real conditions as we have in the experimental unit we present here. We offer in this work the possibility for other research groups of testing their equipments in this unit and we also show the evolution of the works carried out in the locality of Villar de la Yegua.

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A33

DISPERSION OF RADON IN THE ATMOSPHERE AROUND OLD URANIUM MILL TAILINGS

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We have carried out integrated radon-222 and its daughters measurements in the atmosphere around old tailings aiming at estimation of the influence of inactive uranium sites to the population and personnel. These tailings are situated in the area of a former uranium milling activity on the Pridniprovsk Chemical Plant in the city of Dniprodzierzhinsk. The radon-222 measurements have been carried out using the etch track system TRACK 2010Z. The minimum detectable activity of radon-222 was 2 Bq/m^3 at the 30-day exposure. Corresponding data sets of radon-222 and its daughters are analysed. We calculated the distribution of radon equilibrium factor (F) – i.e. ratio between radon and radon daughters for investigated site. Our study shows contrast spatial radon-222 dispersion in the atmosphere while radon-222 rise to the background levels. The average value of the equilibrium factor amounts to 0,146 for the undisturbed open atmospheric air. Atmospheric inversions cause significant rise of equilibrium factor that goes up to 0,487. Present research is carried out within the frameworks of the STCU Project No.3290.

A34

HUMIDITY AS AN IMPORTANT PARAMETER FOR THE MEASUREMENT OF RADON AND THORON IN SOIL USING ETCH-TRACK DETECTORS

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Humidity is one of the main problems for radon measurement in soil. Test for application of Radopot and Raduet (commercially available from Radosys Company, Hungary) detectors in humid environment was done at NIRS because Radopot detector has been used for indoor radon/thoron measurements under normal conditions (temperature and humidity) so far [1, 2].

The experiment consisted of two parts: the laboratory and *in-situ*.

During the laboratory part these detectors were exposed in radon and thoron chambers under well controlled values of concentration, humidity and temperature. As a result the information about humidity influence for calibration factor was obtained.

In the case of *in-situ* part two groups of detectors were exposed to soil gas during about one week in the same 3 boreholes of 50 cm depth (repeated 6 times). The first group was sealed using humidity proof bag whereas the other was not sealed. Additionally, humidity and temperature in the borehole were recorded. As a result the ratio of sealed/not sealed detectors was obtained.

In the case of thoron, the situation is more complicated because thoron is not observed if detector is put into the humidity proof bag.

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A35

WATER TIGHT RADON / THORON PROBES AND MONITORS WITHOUT INFLUENCE OF HIGH HUMIDITY, AIR PRESSURE AND TEMPERATURE

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The simultaneous measurements of radon and thoron are only possible using the alpha spectrometry. Pulse ionisation chambers are not very useful because of the bad energy resolution. The only effective method for a sufficient energy resolution is the charge collection of the Radon / Thoron daughters on the surface of a Semiconductor detector. But till now all existing monitors with this measuring principle has the disadvantage of a high influence of the humidity and temperature on the measuring values. All these devices used a correction algorithm or a drying tube.

With an optimised high voltage chamber with electrostatic focus (Ion optics), like in the device RTM 1688-2, it is possible to collect nearly all short living radon/ thoron daughters inside the chamber at the surface of a semiconductor detector. This high electric field is specially designed and the flight time of the ions is so short that the ion neutralisation process in chamber is negligible. Therefore the device has:

- No changes of the sensitivity due to the ambient humidity
- Usage of a drying tube or similar equipment is NOT required!
- High sensitivity at small chamber volume (approx. 3* 32,5 ml=130 ml)

Special attention was paid to quality assurance. Each stored data record contains a complete Alpha spectrum, which shows the error-free operation of the instrument for each single integration interval. Any number of measurement series may be created by starting/stopping the data acquisition. PC can read the data stored within the instrument even if a measurement is in progress. As a matter of course the instrument is equipped with sensors for temperature, humidity and barometric pressure. An integrated tilt detector will give a signal if the instrument is removed from its original position during the measurement.

Radon entry paths can be discovered by the "sniffing" mode. Soil gas sampling as well as radon in water measurements are simple because of the built-in pump.

The operation of the instrument is realised by only one button. A serial printer may be connected to the interface of the RTM1688-2 to provide a protocol directly on site.

The instrument can be directly connected to a modem (analogue, ISDN, GSM) for remote data transmission. The Radon Vision Software (included in delivery) handles the telephone connection as simple as a direct cable link.

A watertight version with a fast gas transfer entrance window (diffusion time lower 1 min) and watertight housing is available. With 4 built-in measuring chambers it is the main application radon /thoron monitoring in uranium mines or other places with high humidity or in aggressive environment. The RTM1688 Geo version consists of the watertight water soil probe (76 mm diameter) and the watertight electronic part including GSM-Modem for geological applications like soil gas or water borehole measurements and easy data transfer. Other versions are the watertight Analogous Radon Indoor sensor or the Analogous water/ soil probe with 0-1 V or 4.20 mA analogue output. This device can be integrated in existing SBS control system or combined with Data Acquisition systems like MEDAS.

A36

RADON DECAY PROCUTS IN BOUNDARY LAYER OF THE ATMOSPHERE

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National Institute for Nuclear, Chemical and Biological Protection (SUJCHBO, v.v.i.) investigates behavior of radon decay products in boundary layer of the atmosphere starting at least from 1990. Measurement of EER (equilibrium equivalent of radon) was performed in places with different exhalation of radon from subsoil. Grab sampling method as well as continuous measurement were applied in differing areas.

It was discovered, that values of EER in Central Europe are on similar level in the synchronous time. Not only that, comparing results from Czech Republic and abroad in the same time, similar tendencies of EER in boundary layer of the atmosphere was observed.

The measurements were carried out in meridian line from Berlin (Germany) to České Buďějovice (south of Czech Republic). The distance between these two towns is approximately 500 km. Values of EER in all cities between these two points were not differing too much. The ration between 8 a.m. and 7 a.m. was 0.9 ± 0.3 and between 9 a.m. and 7 a.m. was 0.66 ± 0.29. This similar trend was also found during other measurements.

Three places, which were affected by uranium mining in the past, were studied by continuously working instruments (very low background is needed). These measurements lasted for one month. The results show the similar trend in behavior of EER in these three places.

It is not a new idea that the strong wind will cause decreasing (homogenization) of radon in the atmosphere.

There measurements of EER in different highs above the ground: 0.3 m, 3 m and 6 m were organized. The values on the lowest level were 1.2 ± 0,3 times higher than the values in the higher floors. From the results it was evident, that the strong wind plays an important role in reduction of EER.

The influence of height to radon concentration above the ground was studied by using the solid-state nuclear track detectors (SSNTD) in diffusion chamber. Detectors were placed on an iron construction in a chain up to 6 m and fixed to a chimney in a line up to 40 m high. The measurements were performed for 6 months. The first experiment (0-6 m) shows the negligible decrease of radon concentration. In contrary the results obtained in the case of detectors on chimney are a little controversial (the decrease was observed).

This research is supported by State Office for Nuclear Safety (SUJ 200402).

A37

RADON MEASUREMENTS IN SOIL, WATER AND INDOOR ATMOSPHERE OF BUDHAKEDAR IN GARHWAL HIMALAYA, INDIA

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Environmental radiation exists as a consequence of cosmic, terrestrial and man-made sources. Terrestrial radiation is emitted from natural radionuclides present in various amounts in all types of soils, rocks, air, water and other environmental materials. Main source of environmental radon is the soil surface, although secondary contributors include the oceans, natural gas, geothermal fluids, volcanic gases, ventilation from caves and mines, and combustion of coal. Radon was measured in soil–gas and groundwater in Budhakedar area of Garhwal Himalaya, India using radon emanometer. Measurements of indoor radon, thoron and their daughter products were carried out in the houses of the same area for four different seasons (autumn, winter, summer and rainy) using LR–115 plastic track detectors. The track detector is fixed in a twin chamber radon dosimeter, which can record the values of radon, thoron and their decay products separately. The film fixed in bare mode holder gives the concentrations of radon, thoron and their progeny while the films fixed inside the cup with filter and membrane modes give the concentrations of radon/thoron gases and of pure radon gas, respectively. The detailed analysis of the effects of seasonal variation of radon, thoron and their decay products inside the houses is reported in this paper.

A38

PSYCHOSOCIAL FACTORS INFLUENCING THE RADON MITIGATION PROGRAMME

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The Radon Programme in the Czech Republic has been developed and optimised for decades. One of the main aims of the Programme is to carry out the remedial measures in the buildings with elevated indoor radon concentrations. Technical solutions have been developed and their efficacy has been validated. The effectiveness of the mitigation programme, however, is strongly influenced by psychological and sociological factors. Three main problems solved in this process are presented: motivating of building owners to undertake the measures, enforcing the application of certified technical solution and the quality of the building work, and last but not least ensuring the long-term durability of the remedies carried out.

A39

RADON WATERS IN THE AREA OF URANIUM MINERALISATION AND DEPOSITS IN MALÁ ÚPA – KOWARY REGION (CZECH – POLISH BORDERLAND, SUDETES)

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In 2008 an international cooperation between Czech Republic and Poland was started. The subject of this cooperation is the occurrence of radon in groundwaters of the Sudety Mountains. The first stage of research was conducted in the area of Horní Malá Úpa – Kowary region (Giant Mountains range) in the years 2008 and 2009. Investigations were performed by the scientists and MS students of the Charles University (Prague, Czech Republic) and of the Wrocław University of Technology (Wrocław, Poland).

Field-spectrometers were used to identify the locations where background radiation is higher. Any associated groundwater manifestations – springs, wells or other outflows – were then sought. There are some abandoned adits on the Polish side, as parts of former uranium mines. At these places also outflows of mine waters were investigated, as well as water outflows inside the accessible parts of the adits, shafts and galleries. The sites of groundwater finding were described and photographed, their coordinates were read using GPS and marked both on the topographical and geological maps. Water temperature, pH and electric conductivity were also measured. Groundwater samples were collected for field and laboratory measurements of radon (^{222}Rn) activity concentration. In the field, the emanation method, combined with an ionisation chamber, was used while, in the laboratory, the liquid scintillation technique was applied as the reference method.

We are mostly interested in groundwaters with ^{222}Rn activity concentrations exceeding the limit necessary for their potential use for curative purposes, i.e. 1192 $Bq \cdot dm^{-3}$ according to the Czech and 74 $Bq \cdot dm^{-3}$ according to the Polish regulations.

Few outflows of groundwater with more than 2000 Bq dm^{-3} have so far been found and described. These are a spring and a well on the Czech side, and the outflows into the abandoned adits and galleries on the Polish side. These groundwaters may be applied for balneo-therapeutic purposes. However, according to suggestions and directives of international organisations (i.e., WHO, IAEA, European Commission) they should not to be used as tap water or water for domestic use.

A40

LABORATORY FACILITY (RTD) TO STUDY RADON TRANSPORT THROUGH MODELLED SOIL BED: RESULTS OF PRELIMINARY MEASUREMENTS

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The paper describes a laboratory facility (Radon Transport Device - RTD) which makes it possible to study radon transport. The measuring position is a vertical cylindrical vessel with the height of 202 cm and the diameter of 24 cm. It can be filled with sand, gravel or other soil materials to be studied. The facility is providing radon gas from the source to the studied material and making possible the measuring of radon concentration at different vertical distances from the source. The parameters of the medium (temperature, humidity) can be measured at the same time. The preliminary measurements using the RTD with sand as medium are presented.

A41

POSSIBLE ROLE OF RADON IN PREBIOTIC CHEMISTRY AND IN EARLY EVOLUTION OF LIFE ON EARTH

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Radon in the environment of early Earth was present in sites, determined by location of deposits of uranium, in very different geological formations. Estimation of possible concentrations and yields of radon billions years ago is difficult, but it is certain that it was high and was continuously diminishing to the present levels. The best, quantitative back extrapolation of presence of radioactive elements is done for concentration of ^{235}U, which was high enough in some places to give rise to formation of natural nuclear fission reactors (e.g. Oklo phenomenon in Africa). The main role of ionizing radiation in prebiotic chemistry and biological evolution was played by low LET radiations, as deep penetrating sources of external energy. High LET radiations are of low penetration and could act only superficially. Radon is an exception, due to its easy transfer in the air. Therefore it could play a role already in cases of these early organisms which exhibited the gaseous exchange of chemical compounds with the surrounding atmosphere. The action was destructive but, on the other hand, was also mutagenic. Presented considerations are part of the chapter by present Author on the role of nuclear and radiation chemistry in astrobiology, in a monograph, in preparation by American Scientific Publishers. The author was Member of Management Committee in COST Action "Prebiotic Chemistry and Early Evolution" (2004-2008) and is presently Member of MC in the continuation of COST Action, this time named "Systems Chemistry" (2009-2012).

POSTER PRESENTATIONS

P1

TEMPORAL VARIABILITY OF RADON-222 IN NEAR-GROUND ATMOSPHERE

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Radon-222 is an alpha-emitting radioactive inert gas with the half-life of 3.8 days. It is a product of decay of ^{226}Ra which belongs to ^{238}U-decay series. Uranium-238 and its decay product ^{226}Ra are ubiquitous in the upper Earth's crust and in the soils. Radon-222 which is being released into the pore space of soils, diffuses into the atmosphere where it decays to lead ^{210}Pb through intermediate chain of short-lived radionuclides (^{218}Po-^{214}Pb-^{214}Bi-^{214}Po). The release rate of ^{222}Rn is controlled by source term (^{226}Ra content in the soil and its vertical distribution) and by physical properties of the upper soil layer (mineral structure, porosity, water content).

Concentration of ^{222}Rn has been measured quasi-continuously in Krakow since June 2004 with the aid of radon monitor based on detection of daughter products of this gas. The radon monitor has been calibrated against AlphaGUARD detector. The air intake is located ca. 20 meters above the ground, on the roof of the Faculty building. The radon monitor provides individual readings every 30 minutes, representing average activities of ^{222}Rn over 30-minute sampling intervals. In the same location, quasi-continuous measurements of CO_2 and CH_4 mixing ratios in the local atmosphere are performed.

Rn-222 exhibits substantial seasonal and diurnal fluctuations. The absolute amplitude of the recorded individual ^{222}Rn concentrations reached approximately 40 Bqm^{-3} during the 4-year observation period. The maximum of monthly mean ^{222}Rn concentration occurs usually in October (ca. 10 Bqm^{-3}), while the minimum is recorded in March or April (ca. 2.5 Bqm^{-3}). Daily mean values of ^{222}Rn concentration fluctuate between ca. 1Bqm^{-3} and 18 Bqm^{-3}.

Influence of various factors on the observed variability of ^{222}Rn concentration in the near-ground atmosphere in Krakow on different time scales (diurnal, synoptic, seasonal) was investigated. The following parameters were considered: (i) stability of the lower atmosphere largely controlling diurnal variability, (ii) wind speed, (iii) temperature, (iv) fluctuations of atmospheric pressure, (v) history of air masses, (vi) fluctuations of water table and water content of the soil column.

P2

WEAK SEISMICITY AS A RADON DANGER FACTOR TO YEREVAN

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The article deals with relation between the indoor air radon concentration and local seismicity in Armenia, in the period from 2005 to 2006. Radon concentration was measured on a daily basis in Yerevan (in basement of the Ecocenter, located not far away from the Yerevan flexure) and, in addition, data on earthquakes were collected that occurred in the Armenia's territory during this period.

Results have shown a substantial increase in indoor radon concentration (for several times exceeding the antional sanitary level of 200 Bq·m^{-3}) related to seismicity, not only to earthquakes with magnitudes of $M \geq 4.5$, but also those of M ≥ 2.0, being local (70–100 km far from Yerevan) and with small-depth (5–15 km), particularly when occurring in swarms.

P3

ACCREDITED CALIBRATION RADON LABORATORY IN CLOR. INTERCOMPARISON OF TRACK DETECTOR SYSTEMS WITH CR-39.

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Description of the management system implemented in the Radon Dosimetry Group (RDG), Central Laboratory for Radiological Protection, Warsaw, is presented. RDG is accredited in Polish Center of Accreditation as a calibration laboratory in the scope of: radon concentration in air, radon exposition, potential α energy concentration (PAEC). In particular, characteristics of the radon calibration chamber and the calibration procedures for radon devices and detectors and radon progeny devices are provided. The chamber is applied, among others, for performing intercomparison exercises for other Polish radon laboratories. The results of the recent intercomparison measurements for track detector systems based on CR-39 foils, being applied in six Polish laboratories, are presented.

P4

THE USE OF LR-115 TRACK DETECTORS FOR RADON MEASUREMENTS IN RESIDENTIAL HOUSES

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Radon and its short-lived decay products in the atmosphere are the most important contributors to human exposure from natural sources. About one third of the total radiation dose to humans is due to inhalation of short-lived radon progeny in the indoor atmosphere.

The activity concentrations of radon/thoron and their progeny are largely influenced by factors such as topography, type of house construction, building materials, temperature, pressure, humidity, ventilation, wind speed, and even the life style of the people living in the house.

In this work the monitoring of ^{222}Rn was carried out in 88 houses of Opole and Strzeleczki commune (situated approx. 35 km in south direction from Opole). The passive detectors LR-115 type II films (Kodak, Pathe) have been used. The measurements were carried out in residential houses in time period from 2006 to 2007. The detectors were placed in kitchens, bathrooms, cellars and living rooms. During three winter months the detectors remained in the investigated rooms. In some houses the experiment was continued in summer.

Our results showed that in all of the rooms examined the Rn activity did not exceed 265 Bq m^{-3}. This value is lower than the European Commission recommendations for the existing buildings (Commission recommendation 90/143/Euratom, 21.02.1990). Significant influence of the yearly seasons on ^{222}Rn activity was asserted. In winter radon activities were remarkably higher than in summer. No significant differences in ^{222}Rn activity in kitchens and in bathrooms was affirmed but in cellars, activity was higher than somewhere else.

A part of measurements were carried out with help of teachers and pupils from the Strzeleczki grammar school.

P5

STATISTICAL PROCESSING OF RADON VOLUME CONCENTRATION IN DWELLINGS

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The radon volume activity in buildings is generally time variable. Its variability is caused by many natural and man-made factors. An example of these factors includes meteorological parameters, soil properties, characteristics of the building construction, properties of water used in the building and also the behavior of inhabitants. These factors can influence each other and also they are related with the exposition of inhabitants.

The general radon concentration in a building is given by a relationship between a radon entry into the building and its removing from indoors by the escape through constructions, ventilation or a radioactive decay.

This article reports a continual indoor radon monitoring and a statistical evaluation of a dataset obtained by the measuring in a house located in the Czech Republic. The object of measuring partly included the basement building. The main source of radon was the soil.

The current meteorological parameters were also measured during experiments. Especially an effect of indoor and outdoor temperature differences in relation with the indoor radon are analyzed in this contribution. Results of time series analyses of the continual indoor radon and the meteorological monitoring are presented and discussed as well.

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P6

2ND INTERNATIONAL INTERCOMPARISON OF RADON AND THORON PASSIVE DETECTORS AT NIRS

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An international intercomparison of integrating detectors for radon and thoron was conducted at NIRS (National Institute of Radiological Sciences, Chiba, Japan). 28 groups from 16 countries [Figure 1] participated in this experiment.

Various types of passive detectors, like CR-39, PicoRad and E-Perm, were used for this purpose. All detectors were simultaneously exposed to radon/thoron gases in the calibration radon/thoron chamber under well controlled conditions of temperature and relative humidity as well as radon and thoron concentrations.

During the radon intercomparison, the participants inter-compared their detectors under 3 exposure conditions (low - 100 kBq h m-3, medium – 500 kBq h m-3 and high – 1000 kBq h m-3). Radon concentration was monitored using AlphaGUARD radon monitor certified by PTB. In the thoron intercomparison 2 exposure conditions (500 kBq h m-3 and 1000 kBq h m-3) were carried out and RAD7 monitor (calibrated by a scintillation cell method in the NIRS [1]) was used as a reference one.

The next (3rd) intercomparison is planned this year. We cordially invite you to attend it.

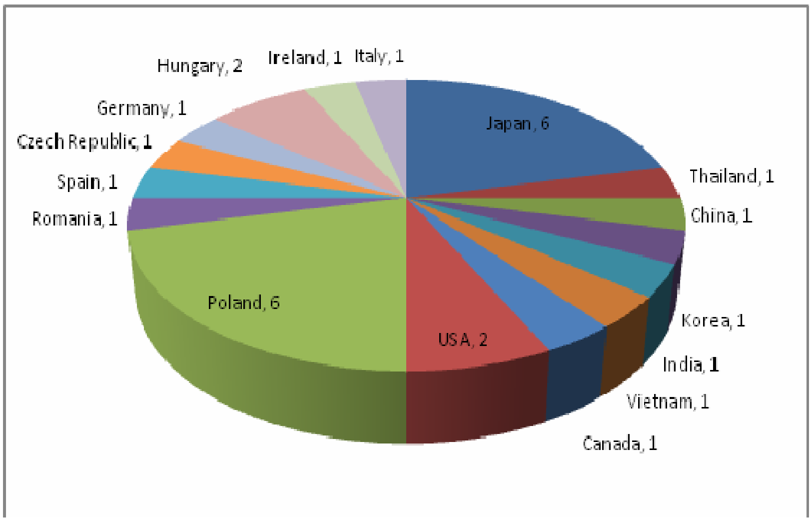

Figure 1. The countries participating in the intercomparison

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P7

RADON CONCENTRATION IN SOIL GAS IN IDRIJA, SLOVENIA

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The town of Idrija in western Slovenia, known for mercury mining and milling, is situated on different geological layers, such as dolomites, shales, Gröden funds and limestones, being formed in the period from creda to permocarbon. This geological heterogeneity has attracted an enhanced interest for measurements of radon concentration in soil. The main purpose of our study was to define the radon index, which will help designers and constructors to assure acceptably low indoor air radon levels in the buildings to be constructed. Depending on the geological basis, radon concentrations differred from location to location, ranging from several kBq m^{-3} up to 70 kBq m^{-3}. Based on our results, radon index in the range 2–3 has been defined.

P8

SEASONAL CHANGES OF INDOOR RADON (^{222}RN) CONCENTRATIONS OF POLAND – ASSUMPTIONS, PURPOSES AND METHODS OF THE PROJECT

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Radon (^{222}Rn) is a noble radioactive gas produced in the course of radium (^{226}Ra) disintegration. Indoor radon concentration undergoes seasonal changes. There are many factors that influence these changes, including the type of soil and climate. In order to estimate the exposure of inhabitants, mean annual radon concentration should be known. The studies were to establish changes of concentration of this gas through annual observation and improve methods of evaluation of mean annual radon concentrations. It can be obtained on the basis of shorter measurements using calculated national and/or regional corrective monthly and/or quarterly coefficients. It would allow to shorten and thus to lower costs of determination of mean annual radon concentrations in dwelling houses. The results of simultaneous measurements carried out in numerous regions of the country would allow to establish a particular radon map of Poland and Europe.

The project executors are from institutions that work for the Radon Center - the Non-governmental International Scientific Network and deal with examination, measurements, and variety of issues concerning radon and its occurrence in the environment. The whole territory of Poland underwent the measurements. Buildings with increased radon concentrations were included in the studies. The constructive features of the buildings and construction materials were described. We gathered data concerning geological substratum, on which the houses were set. The measurements started in February 2008. During one year, one room in each house was exposed with 3 monthly-detectors or 3 quarterly-detectors. Thus, we obtained radon concentration values measured for 12 months and for 4 quarters. Weather, temperature, and indoor pressure parameters were observed simultaneously. Trace detectors CR-39 in diffusion chambers were used in the study. The following centers/institutions perform radon concentration measurements: Central Laboratory of Radiological Protection in Warsaw, Institute of Nuclear Physics PAN in Kraków, The Central Mining Institute in Katowice, The Nofer Institute of Occupational Medicine (NIOM) in Łódź, Wroclaw University of Technology in Wroclaw and Medical University of Białystok. These institutions participate in comparative measurements in order to provide results of appropriate quality.

Funding for this research was provided by Polish Ministry of Science and Higher Education under grant No.N506112733.

P9

RADON LEVELS AND RADIATION DOSE ESTIMATES IN THE CAVES OF THE BAKONY MOUNTAINS (HUNGARY)

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Nowadays, as the practice of extreme sports continues to spread, potholing is also becoming more and more popular. As a result, not only the number of cavers, but the time spent in caves, is on the rise. There are some cavers known to have spent some 5,000 hours in caves in a span of 10 years. Radons exhaling from cave rocks and deposits may accumulate in poorly ventilated caves, thus causing a significant radiation dose for the cavers.

In this study, radon concentration in air was measured in seven caves in the Bakony Mountains in Hungary. Active and passive measurement techniques were used. Radon concentrations in air of different caves were rather different, varying between 50 and 24,000 Bq m^{-3}. The average value obtained in five of seven caves included into our survey was approximately 10,000 Bq m^{-3}.

Assuming an average of 470 hours spent yearly in caves, radiation doses received by active cavers were estimated. Using 0.60 for the equilibrium factor between radon and its short-lived decay products, the expected annual effective dose was 19.7 mSv. Based on these results, even a dose of 100 mSv seems possible for a five year period. Therefore, it is advisable to monitor radon in all frequently visited caves and to encourage active cavers to use personal radon dosimeters.

P10

RADON AND THORON PARALLEL MEASUREMENTS IN DWELLINGS NEARBY A CLOSED HUNGARIAN URANIUM MINE

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Radon (^{222}Rn) and thoron (^{220}Rn) integrated measurements were executed in a Hungarian village, Kővágószőlős, located in the Mecsek Mountains in the southern part of the country. There is a closed uranium mine in vicinity of the village, with some haulageways and galleires even under the village. The RADUET passive radon and thoron monitor was used. It is a twin detector based on CR-39, composed of two practically identical parts, one to detect radon only and the other to detect both radon and thoron. The two parts are implanted in a cardboard holder to keep appropriate distances from the wall. The detectors were evaluated at the National Institute of Radiological Sciences (NIRS), Chiba, Japan.

The investigated houses were one storey buildings made of brick. The rock under the village is gray-sandstone. The analysis of the drill cores taken from a depth of 1–2 m in the soil of the village showed the average uranium and thorium contents of 136 and 77 Bq kg^{-1}, respectively. These values exceed world averages (i. e., 33 and 45 Bq kg^{-1}, respectively).

The detectors were mostly placed in the inhabited parts of houses, such as bedrooms and living-rooms, at a height of 1–1.5 m above the floor.

The measurement periods were from December 2006 to May 2007 and from May 2007 to February 2008.

Results have shown that radon concentrations are significantly higher than the Hungarian average for dwellings.

The thoron concentrations are not negligible, and so are not thoron contributions to the effetcive doses. Additionally, this ia a warning that radon measurements, using detectors sensitive also o thoron, may be misleading.

P11

IDENTIFICATION OF RADON ANOMALIES IN SOIL GAS USING DECISION TREES AND ARTIFICIAL NEURAL NETWORKS

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Radon (^{222}Rn) activity concentration was measured in soil gas at a depth of 480 cm in a borehole at the Orlica fault in the Krško basin in SE Slovenia, over a period of 32 months. In addition, environmental parameters, such as soil and air temperatures, barometric pressure and rainfall were recorded. During this period, 11 local earthquakes occurred of $M_L \geq 1.5$. The time series of the measured data was analyzed by applying machine learning methods: decision trees and neuron networks. The series was divided into two subsets: (i) the seismic activity subset (SA), comprising the data recorded during periods lasting from *n* days before to *n* days (*n* varying from 1 to 10 days) after the occurrence of a seismic event, and (ii) the non-seismic activity subset (non-SA), with data remained after subtracting the SA subset. In using both methods, the program was taught to predict radon activity concentration based on the non-SA subset of the environmental data. Then, the entire series was subjected to the analysis and the prediction was expected to fail during seismic periods. By appropriately chosen analytical conditions, a statistically significant difference (CA radon anomaly) between the measured and predicted values of radon concentration was observed for all earthquakes. On the other hand, anomalies were seen also during non-seismic periods (FA anomalies). The present efforts are aimed at minimizing the number of FA anomalies while keeping the number of CA anomalies unchanged.

P12

A RADON ANOMALY IN SOIL GAS AT CAZZASO, NE ITALY, AS A PRECURSOR OF A M_L = 5.1 EARTHQUAKE

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At the town of Cazzaso (Friuli) in northeast Italy, radon (^{222}Rn) activity concentration in soil gas in a borehole at a depth of 80 cm has been monitored continuously (at a frequency of once an hour) since May 2004, using a Barasol probe (ALGADE, France). In addition, environmental parameters (air and soil temperature, barometric pressure) have been recorded. Statistical analysis of the time series of the data has revealed that, in periods of elevated seismic activity in the region, radon activity concentration may deviate by more that two standard deviations from the average value of 2.6 kBq m^{-3} over the entire period of measurement. One such deviation anomaly, with a maximum radon concentration of 35 kBq m^{-3}, is seen in the period from October 31 to November 9, 2004, started about three weeks prior to the M_L = 5.1 earthquake happened on November 24 with epicentre 250 km distant at the Garda Lake. It was felt over a wide area of the North Italy. According to Hauksson and Goddard selection, some lower deviation anomalies have been observed before other earthquakes with lower magnitudes. The seismicity has been considered too by the *b* parameter of the Gutenberg and Richter law, expression of a mean seismic activity related to the geodynamic process. Before the Garda Lake earthquake the *b* value decreased according the dilatancy theory. A detailed analysis of the time series, applying machine learning methods (decision trees and neuron networks), is in progress.

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P13

URANIUM, RADIUM AND RADON ISOTOPES IN SELECTED BRINES OF POLAND

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Studies of natural radioactivity in nine intakes of different types of brines from five localities in Poland were performed. Brine is a highly mineralized groundwater containing higher amounts of natural radioactive isotopes. Investigated brines from different locations in Poland are exploited from various geological structures composed of rocks of different chemical and mineral composition as well as different age and depth. All investigated brines are used in balneotherapy (i.e. baths, inhalations, showers). The main goal of this study was to obtain some basic knowledge on the activity range of natural isotopes of U, Ra and Rn in different brine types in Poland and their variability depending on their location in certain geological structures.

In order to obtain the necessary data, two different nuclear spectrometry techniques were applied. Activity concentrations of radon (^{222}Rn) and radium isotopes (^{226,228}Ra) were determined by using the WinSpectral α/β 1414 Liquid Scintillation Counter (Wallac). The chemical procedure for radium isotopes determinations was based on radiochemical preconcentration of radium from samples by coprecipitation with $BaSO_4$ and purification of its derivatives. Uranium content (^{234,238}U) was measured by using the 7401 VR α–spectrometer (Canberra – Packard, USA), equipped with the silicon surface barrier detector. The alpha sources were prepared by coprecipitation with NdF_3.

The activity concentrations of ^{222}Rn vary from below 1 to 76±4 Bq dm^{-3}, of ^{226}Ra from 0.19±0.01 to 85.5±0.4 Bq dm^{-3}, and of ^{228}Ra from below 0.06 to 2.17±0.09 Bq dm^{-3}. For uranium isotopes, the concentrations are in the range from below 0.5 to 5.1±0.4 mBq dm^{-3} for ^{238}U and from 1.6±0.4 to 46±2 mBq dm^{-3} for ^{234}U. The obtained results indicate high radium activity concentrations corresponding to high mineralization of waters. This fact had been observed in previous investigation of waters of different origin [1].

Ref.

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P14

SEASONAL AND DIURNAL VARIATION OF OUTDOOR RADON (^{222}Rn) CONCENTRATIONS IN URBAN AND RURAL AREA WITH REFERENCE TO METEOROLOGICAL CONDITIONS

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The objective of the study was to investigate temporal variability of outdoor radon (^{222}Rn) concentration registered in the centre of Lodz, in Ciosny village (rural area, 25 km to the north of Lodz, in Cracow (north-west part of the city, suburban area, Institute of Nuclear Physics PAN) in relation to meteorological parameters (i.e. air temperature, temperature gradient, wind speed, soil heat flux, volumetric water content in soil) with special consideration of urban-rural differences. Continuous measurements of ^{222}Rn concentration (in 60-min intervals) were performed 2 m above the ground using AlphaGUARD® PQ2000PRO (ionisation chamber) from January to December 2008.

^{222}Rn concentration through the year did not exceed 20 $Bq \cdot m^{-3}$ (in Lodz), 35 $Bq \cdot m^{-3}$ (in Ciosny) and 43 $Bq \cdot m^{-3}$ (in Cracow). The daily pattern of ^{222}Rn concentration at 3 stations was revealed with maximum at 06.00-07.00 a.m and minimum at 15.00-17.00 p.m (Fig.1). Negative urban-rural differences of ^{222}Rn concentration were found. The differences increased from spring to summer and during nocturnal hours till sunrise. The maximum contrasts of ^{222}Rn between Lodz and Ciosny, reached -30 $Bq \cdot m^{-3}$, were registered in June and July during phenomenon of Urban Heat Island. The increase of ^{222}Rn concentration was observed with increase of soil heat flux and of temperature gradient (t°C at 2m level - t°C at 0.2m level) when temperature inversion occurred near the ground. ^{222}Rn concentration characterized of opposite course to air temperature, water content in the soil and wind speed.

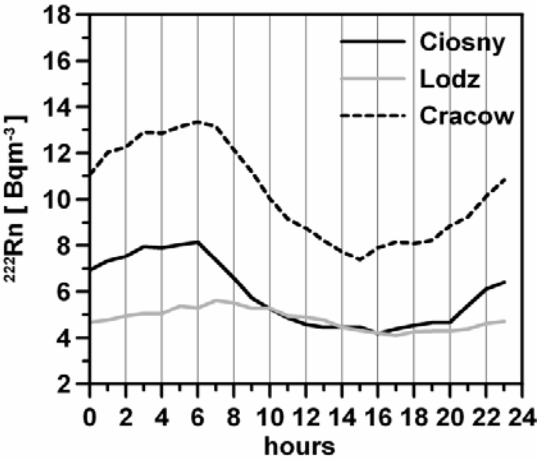

Fig.1. Daily mean course of radon (^{222}Rn) concentrations in the air 2 m above the ground in Ciosny (rural area), in the center of Lodz and in the north-west of Cracow in 2008

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P15

RADON IN OUTDOOR AIR AT Mt. ETNA VOLCANO, ITALY

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Activity concentration of radon (^{222}Rn) in outdoor air at a height of 20 cm above the ground was measured in the area of Mt. Etna volcano, Italy, using the AlphaGuard radon monitors. Measurements were taken at different distances and in different directions from the volcano summit, and on lava flows of various ages. High values, up to 93 Bq·m^{-3}, were found at the measurement points closest to the summit craters, at altitude of about 3000 m a.s.l. Conversely, radon activity values were low, in the range 3.0–19.6 Bq·m^{-3}, at the other 22 points on the volcano flanks. Values were lower towards the seaside and higher towards the inland. We divided the volcanic area into four sectors (North, South, East and West) and the respective averages of radon activity were: 4.8 Bq· m^{-3} for East, 6.5 Bq m^{-3} for South, 7.9 Bq·m^{-3} for North and 8.6 Bq·m^{-3} for West. Evaluation of the influence of geology, tectonic faults and volcanic activity on the local outdoor radon level is underway.

P16

RADIOMETRIC MEASUREMENTS ON FLY ASH AND SLAG BEARING BUILDING MATERIALS - A HUNGARIAN CASE STUDY

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By-products of industrial production processes are used ever more often in national and international construction technologies as building materials on their own or as additives to building materials. There is a considerable number of known examples, both from national and international results, revealing cases of building materials or tiles containing coal slag and fly ash, all potentially dangerous for human health due to their content of some natural and artificial components.

A statutory act put in place in 1960 by the Ministry of Construction of Hungary (which, however, has later been repealed) banned the use of coal slag containing high levels of Ra concentration as building materials. Even so, different types of coal slags have not ceased to be utilized as building materials at private and at public construction sites. In Hungary, currently a Government Order and Ministry for Health Order are set to regulate building materials related issues, none of which are setting threshold values for unacceptable levels of radioactive radiation. Nor does any statutory rule exist for setting the maximum level of radon concentration allowable in premises.

In Hungary, from a radiological point of view, one of the most important issues is the utilization of the different types of coal slag and fly ashes as building materials. Therefore, the main aim of this study is to analyze gas silicate and coal slag concrete samples from five different locations within the central part of Hungary, using radiometric and geochemical methods.

During laboratory analysis, the ^{238}U-, ^{232}Th- and ^{226}Ra content has been measured by HPGe Gamma-spectrometry and the radon production was measured by Rad7 continuous radon monitor. On the thin sections, made from the coal slag and gas silicate samples, microscopic description and observation, mineralogical/phase composition and porosity estimates have been performed. To identify the chemical composition of the building materials, scanning electronmicroscope measurements have been used. The results have indicated that, due to the nature of coal slag and fly ash production techniques, both natural and artificial components can be found in building materials. On the other hand, the most frequently identified mineralogical phases are quartz and calcite. It has also been ascertained that fly ashes, and the coal slag concretes produced using both contain carbon, glass and metallic phases that have iron as their primary constituent. Iron and the different carbon phases adsorb Ra, Th and U well. In the samples analyzed, there is also a high probability of U and Th containing monazite ((Ce,La,Nd,Th)PO_4) and xenotime (YPO_4) minerals appearing.

P17

INVESTIGATION OF NATURAL RADIOISOTOPES ACTIVITIES IN FOREST SOIL HORIZONS

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The knowledge of the distribution and of the behaviour of the radionuclides in soil, is important in understanding several issues of the natural environment, eg the exchange of radionuclides between the soil solid matrix and surface and/or ground waters, the exchange of radionuclides between the upper soil layers and the atmosphere.

Activities of radioisotopes were measured in samples of forest soil. The samples were collected in forests situated along the roads from Złoty Stok (PL) to Hradec Králové (CZ). The samples of forest litter and then soil profiles from ground level down to 35-40 cm depth were taken. Each soil profile was separated into individual horizons. After homogenization the activities of radioisotopes were measured in the sample of each soil horizon. Activities of the following radioisotopes were determined by gamma-ray spectrometry: ^{214}Pb, ^{214}Bi, ^{231}Th, ^{235}U, ^{212}Pb, ^{212}Bi and ^{228}Ac.

Distributions of the data concerning radioactivities were positively skewed. The lowest activity was found for ^{235}U (median value was 2.25 Bg/kg) and the highest one for ^{228}Ac (16.26 Bg/kg in median). Activities of ^{231}Th and ^{235}U were similar in all of soil horizons examined. For the remaining radioisotopes lower activities were found in organic horizons than in inorganic horizons.

It was found that activities of the radioisotopes from the same decay chain were well correlated. But for some radioisotopes belonging to different decay chains a good correlation was also affirmed.

P18

MEASUREMENTS OF RADON CONCENTRATIONS IN GROUND WATER SAMPLES OF TECTONICALLY ACTIVE AREAS OF HIMACHAL PRADESH, N-W HIMALAYAS, INDIA

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The paper discusses the results of systematic measurements of activity concentration of radon in ground water samples from seismically active areas of N-W Himalayas, Himachal Pradesh, India. Water radon concentrations were measured using RAD-7 equipped with an appropriate unit (Aqua kit) following a protocol proposed by the manufacturer. For systematic study, the selected area has been divided into three Zones on the basis of lithology and thrust systems of the area. The radon concentration in water samples collected from Zone-I has been found to vary from 8.4 Bq/l to 314 Bq/l. The radon concentration in water samples collected from Zone-II has been found to vary from 14.4 Bq/l to 140 Bq/l .The radon concentrations in water samples collected from Zone-III has been found to vary from 9.3 Bq/l to 70.8 Bq/l.

P19

APPLICATION OF RADON EMANATION SURVEY FOR THE DISCOVER OF OLD BURIED TAILINGS IN THE POPULATED AREA

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We presented the results of detection and border definition of an old buried tailings on the territory of the populated zone (area of Lazo Str.) of Dniprodzerzhinsk city. The preliminary radiation investigation shows that the radioactive residues are deposited at a depth of 2-3 m below surface and contain radium-226 concentration of about 14000 Bq/kg. This information gave a base to use radon emanation survey for definition of radioactive residues body borders. The strategy of tailings searching in the conditions of minimal prior information about its formation has been developed. The technique of radon in soil gas measurement and the equipment used are described. Soil gas was sampled at depth of 0,6 m. For measurements we have used scintillation cells with volume 50 cm^3. The emanation survey has been supplemented by measuring of radon-222 flux from the soil surface, especially in the places where sampling of soil probe was difficult. Obtained results were used for introducing a classification system for radioactive residues and for developing protective measures.

P20

A LIGHT-WEIGHT LIQUID SCINTILLATION SYSTEM WITH AUTOMATIC SAMPLE CHANGING FOR RADON FIELD MEASUREMENTS

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In geophysical and environmental studies, radon (^{222}Rn) concentration in water, air and emanating soil-gas is frequently measured with the liquid scintillation counting technique. For field work, a light-weight system with automatic sample changing is desirable. We describe a new automatic (10) sample changer with a single phototube detector for this type of work. Its weight (without the lap computer) is 3 kg and it can be operated for a week on a 10 kg lead accumulator. Very low background is obtained by registering only the alpha disintegrations of ^{214}Po through pulse time analysis.

P21

RADON EVENTS IN THE U-MINE ENVIRONMENT AND RELATED RADIATION EXPOSURE

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Environmental impact of the U-mine radon sources on natural radon levels can be rather easily recognised if relevant measurements are available. Namely, sharp and high peaks in radon concentration time series were found in the environment of the former U-mine at Žirovski Vrh (Slovenia) seasonally, being superimposed on normal periodical diurnal radon curves. These peak levels, ranging from a few Bq/m^3 up to a hundred Bq/m^3 and more, represent very clear impacts of the U-mine radon sources (other than natural), and their widths give the duration of these impacts. They are lasting mostly from one to several hours. This can be observed at certain weather situations, at certain times of the day and season and at certain locations only. Short term radon peaks - named as radon events - could therefore exceed natural background at certain spots for several times and are more typical for a warm period.

The aim of this paper is to present approximate levels of radiation exposure of single radon events received by representatives of the nearby population. The exposures were estimated for individuals who really might have been staying near the fence of the controlled area at times for some hours during their work (haymaking, cutting and gathering wood, picking blackberries and mushroom, fishing) at the time of the radon event.

Uranium mining and milling at Žirovski Vrh were carried out from 1985 to 1990. After cessation, the underground mine was closed, but several disposal sites with bare areas remained, among them a large mine waste rock pile and a large tailings pile, both at elevated positions above the valley. As for the Žirovski Vrh uranium mine impact, radon was found to be the most important exposure pathway since it contributed about 0.2-0.3 mSv to the annual effective dose to the population living at the nearby settlements.

Seven different radon events have been identified within the U-mine environment at Žirovski Vrh, using a network of continuous radon progeny measuring devices. The most significant radon events were found out in the valley at foothills of the mine waste rock pile and in the vicinity of the pile plateau: the estimated exposures range from 3-5 μSv per event. Several times lower exposures per event (0.7-2.4 μSv) were related to the tailings pile, with the highest figure for the event appearing in a zone below the site, with medium levels for the upwards zone and with the lowest for the location at the opposite site of the valley. That means even higher effective doses than received by an individual belonging to the reference group of the light-water nuclear power plant due to its operation during all the year (less than 1 μSv).

P22

RADON LEVELS AFTER RESTORATION OF THE U-MINE DISPOSAL SITE

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Uranium mining and milling at Žirovski Vrh (Slovenia) were carried out from 1985 to 1990 and yellow cake was being produced from the ore with a moderate content of uranium (near 0.1 % U_3O_8). After cessation, the underground mine was closed and not ventilated any more. Two disposal sites (tailings pile and mine waste rock pile) are situated on the hill slopes, each of them has an area of 4 hectares and both were – before restoration started - significant sources of radon., 4 TBq/y and 2 TBq/y respectively.

Mine waste rock from two smaller sites was transported completely to the final disposal site at Jazbec, resulting in a large disposal site of 2.5 million tonnes of material with the grade of about 60 g/tonne U_3O_8. Beside this, red mud from neutralisation process was also deposited on the site in thin layers, containing about 60 % of all ^{230}Th originally present in the processed ore. Adequately shaped disposal site was first of all covered by clay from the local deposit and later with a thick combined layer of inert local material with the overall thickness of 2 metres. The restoration of the mine waste rock site was completely terminated in autumn 2008. The second disposal site, i.e. tailing pile has been still in restoration. Remediation works were primarily oriented to the stabilisation of the sliding terrain and secondly to the restoration of the site from radiological point of view.

The aim of the paper is to present the effectiveness of covering on the restored mine waste disposal site by evaluation of the radon measurements before and after restoration works.

Radon concentrations were measured on site and in the surroundings. Measurement points were extended along the air movement trajectory downstream the main valley. Several measurement campaigns were conducted before the restoration started and also after final restoration of the site, in both cases with passive radon detectors. Radon exhalation was measured on a bare surface of the pile and later, during and after restoration. Differences between the both groups of results are significant, figures obtained now are at least for one order of magnitude lower than before restoration. Actual exhalation rate of radon is much more lower than projected and far from the authorised level of 0.1 $Bq \cdot m^{-2} \cdot s^{-1}$.

The reduction of the radon exhalation rate and its concentrations outdoors has important dosimetric implications. Namely, the estimated exposure for the individuals from the reference group due to radon inhalation pathway was significantly diminished. The same is valid for restoration workers. Further monitoring of radon levels is provided for the next years; after that only institutional control will be established.

P23

AUTOMATIC DEVICE FOR CONTINUOUS MEASUREMENTS OF RADON FLUX DENSITY

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The developed device for continuous measurements of radon flux density from the ground surface is described in this work. This device is used for radon monitoring stations for the purpose of prognoses of earth crust stress-deformed state changes. Method of accumulative chamber was used in the measurement device. The choice of measurement method, detector and a construction of accumulative chamber was determined on the one hand by strict demands to device exploitation conditions, on the other hand by measurement conditions. Schematic diagram of the automatic device for radon flux density measurements and measurement results are presented in this work. Comparison of experimental data measured by developed device with standard technique results (radon radiometer RRA-01M-03, Russian Federation) was made.

P24

SOLUTION OF DIFFUSION-ADVECTION EQUATION OF RADON TRANSPORT IN MANY-LAYERED GEOLOGICAL MEDIA

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The solutions of stationary and nonstationary diffusion-advection equations of radon transport in many-layered geological media by numerical methods are presented. Integro-interpolation method (balance method) was used for construction of homogeneous conservative finite-difference schemes. The obtained explicit and implicit finite-difference schemes were solved by right and left double-sweep methods. The optimal grid pitch was picked out based on comparing of numerical calculations data and analytical solution obtained in "Mathematica 5" pack for a stationary case. The algorithms and programs "SimRaTran" version 1 and 2 for simulation based on the chosen numerical methods in C++ were designed. The programs allow calculating functions of radon pore activity distribution and radon flux density with depth and into atmosphere. Numerical calculations results of radon pore activity function with depth for the three-layer medium represented by different types of soils and rocks with strongly different physical and geological characteristics are represented in the paper. As a conclusion the analysis of numerical simulation results and recommendations for these models applications are presented.

P25

RADON CONCENTRATION BURSTS IN ATMOSPHERE SURFACE LAYER DURING CYCLONES

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The results of many years (2006-2009) measurements of gamma field levels, which are the indicator of radon concentration changes in atmosphere surface layer, are presented and discussed in the work. In 2006 the measurements were conducted at a height of about 2 m above ground surface with a cycle of 1 min. Since 2007 and up to date the measurements have been conducted at a height of about 24 m with a cycle of 0.5 min. Registration of the main meteorological (atmospheric pressure, temperature, relative humidity, wind speed and direction), actinometric (total radiation) and electric (electric field strength and conductivity) parameters of atmosphere was carried out in parallel with measurements of gamma field level. The correlation analysis of gamma-radiation data with current state of atmosphere is presented here. It was established that radon concentration bursts are related with passing of minimal atmospheric pressure regions (cyclones) through measurement point. It was here revealed that radon concentration bursts are registered predominantly in the case of relative humidity jump (up to 100%). Physical reasons for anomalous behavior of gamma field levels are discussed in the paper.

P26

COMPLEX EXPERIMENT METHODOLOGY ON ANALYSIS OF PROCESSES OF SOIL RADON ENTRY INTO ATMOSPHERE

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Comparative analysis of radon transport mechanisms in absolutely different geological zones (Kuril-Kamchatka subduction zone, Western-Siberia plain) and factors regulating its flow and concentration in near-surface atmosphere of the regions with maritime and sharply continental climate requires experimental devices to measure radon field, meteorological atmosphere parameters, space weather factors, geological state changes, elaboration of coherent measurements methods.

Measuring stations of coherent monitoring are placed in Petropavlovsk-Kamchatski geodynamic proving ground and at the eastern outskirts of Tomsk. They include the equipment which allows carrying out continuous automated measurements of physical fields: radon and thoron radiometers, gas-discharge and scintillation counters to measure the flux density of alpha-, beta- and gamma radiation, automated system measuring pressure, temperature, humidity, total radiation, electric field strength, atmosphere electrical conduction, atmospheric turbulence characteristics, total ozone.

Coherent experiment results in the process of analysis are supplemented with space weather current data, spread in INTERNET (solar radio emission flow, Wolf number, geomagnetic activity index).

Coherent experiments methodology includes:

- synchronous experiment methods designed to reveal global external factors controlling the radon field behaviour;
- a method of choice from the coherent monitoring data the measurements carried out under similar meteorological conditions (conditions of "good weather", cyclone, anticyclones, etc.) for each monitoring station;
- a method of choice from the data of synchronous measurements carried out in Kuril-Kamchatka subduction zone during the preparations for seismic phenomena and in seismically inactive region (Western-Siberia plain).

P27

SUBSOIL RADON DYNAMICS IN PERIODS OF INCREASED SEISMICITY OF KAMCHATKA PENINSULA

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Monitoring of radon volumetric activity in soil air has being conducted on the stations network of the Petropavlovsk-Kamchatsky geodynamic proving ground (southern part of Kamchatka peninsula, Russian Federation) since 1997. The peculiarity of this stations network is radon registration in aeration zone on two depths (as a rule, one and two meters below the surface). It allows operating not only with soil radon activity dynamics but with radon flux density from the ground surface calculated from the radon data.

It was observed from the data of almost 10-years stations network functioning:

1. Occurrence of soil radon field anomaly before strong earthquakes with M>5.5 originated in Southern Kamchatka region. The anomalies are considered as a reaction of soil radon field to reorganization of regional stress fields that results in plastic deformations in subduction zone, which stimulate generation of «geodeformation waves».
2. Significant atmospheric pressure variations can serve as a pilot signal to start radon monitoring for the prognosis of stress-deformed state changes.
3. Radon flux density from the Earth's surface is more effective characteristics of radon transport in soil for monitoring of stress-deformed state of geological medium.

With help of the developed applied program "GeoRadon-2" the values of convective velocity and radon flux density were calculated for the period of two month when the strong earthquakes of Southern Kamchatka with K>5.5 occurred.

Based on statistical laws it was found out that the response change of radon flux density to pressure variations occurs before the earthquake, which is connected with cyclones. It concerns a softening medium model at large distances from the future earthquake source due to dilatancy zone.

P28

FILTRATION APPROACH TO MITIGATE INDOOR THORON PROGENY CONCENTRATION

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Increased thoron (^{220}Rn) concentrations reported in Chinese traditional clay dwellings have caused extensive concern. The decay products of thoron, attached and unattached fractions, contribute to a distinct inhalation exposure to the lung due to their high potential alpha energy [1, 2]. In attempt to mitigate the concentration of thoron decay products, thus, to minimize the exposure, alternative methods of filtrations were adopted and investigated. In a thoron model room at Helmholtz Zentrum München, we deployed pumps with varied air flow rates and filter types under the circumstances of natural ambient condition, cigarette smoking, Chinese cooking environment and mosquito coil burning, respectively. Potential alpha energy concentration, aerosol particle number concentration and size distribution were measured simultaneously to assess the filtration efficiency. Furthermore, for detailed dose assessment, attached and unattached thoron progenies were recorded during the filtration process [3].

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P29

MEASUREMENTS OF INDOOR RADON IN THE JELENIOGÓRSKA VALLEY AREA (SUDETY MOUNTAINS) WITHIN THE FRAME OF THE PROJECT "RADON, HOW TO LIVE WITH IT?".

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The radon measurements in dwellings were performed on the area of Jeleniogórska valley (Sudety mountains region) within the frame of the project "Radon, how to live with it?". The project was supported by EU funds and its goal was to widen the knowledge of local community on natural radiation (with special focus on radon). The measurements were performed by the Laboratory of Radiometric Expertise, Institute of Nuclear Physics, Polish Academy of Sciences and were organized by The Polish Ecology Club. The Sudety region is the area where uranium deposits occur. It is directly connected with its geological structure. Therefore it is the region where higher radon concentration can appear. The radon concentrations were checked in about 50 houses (in 20 villages) using CR-39 track detectors (by RadoSys, Hungary). The highest radon concentrations were obtained in cellars, lower values were found on the ground floors and the lowest ones on the first floors with the average values: 1310 Bq/m^3, 220 Bq/m^3, 130 Bq/m^3, respectively. The measured values exceed the average value of radon concentration for polish dwellings – 49 Bq/m^3 (data given by Central Laboratory for Radiological Protection, Warsaw). Additionally, two seminars were organized for the local community.

The first one dealt with the natural radiation in Sudety in general, and the second one reviewed the results obtained.

A PRELIMINARY INVESTIGATION OF ^{222}RN, ^{220}RN LEVELS IN NON-URANIUM MINE, CHINA

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A preliminary investigation of ^{222}Rn, ^{220}Rn levels in non-uranium mine China has been confirmed According to a principle of typical sampling, 44 mines which involved 4 categories, 17 types of mines from12 provinces were selected. The R-T discriminative detectors were used to measure ^{222}Rn and ^{220}Rn concentrations. The results show that ^{222}Rn and ^{220}Rn concentrations both follow the lognormal distribution. The mean ^{222}Rn concentration in 25 metal mines (n=147) was 1211 ± 2359 Bq·m^{-3} (AM), 311 ± 5.5 Bq·m^{-3} (GM), and that of ^{220}Rn was 269 ± 700 Bq·m^{-3} (AM), 71 ± 4.4Bq·m^{-3}(GM). The mean ^{222}Rn and ^{220}Rn concentrations in 18 non-metal mines (n =118) were 98±206 Bq·m^{-3} (AM), 55±2 Bqm^{-3} (GM), 60±76 Bqm^{-3} (AM), 38±2.4 Bq·m^{-3} (GM), respectively. The equilibrium factor for ^{222}Rn was 0.33± 0.15 (underground mine), 0.47±0.18 (open-pit mine). The equilibrium factor for ^{220}Rn ranged from 0.001 to 0.054. The average annual effective dose of the miner exposure to radon and thoron was estimated 8.15 mSv.

SEASONAL VARIATION OF RADON AND THORON IN NON-URANIUM UNDERGROUND MINE CHINA

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A study of seasonal variation of radon and thoron in different kinds of non-uranium mines have been carried out by using LD-P-R-T discriminative detectors. The radon concentrations in underground workplaces showed a significant seasonal variation, and the ratio of radon in summer to that of winter ranged from 2 to 12. For 3-months measurements, the correction factors vary from 0.59 to 1.50. The radon results for short time measurement should be taken into account the season affection. The thoron concentration in underground mines showed a tendency that it was higher in winter and lower in winter. It was difficult to obtain a representative thoron level due to the influence of location of detectors .The seasonal variation of thoron should further studied.

RESIDENTIAL RADON AND LUNG CANCER RISK IN A HIGH-EXPOSURE AREA OF GANSU PROVINCE, CHINA

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In the general population, evaluation of lung cancer risk from radon in houses is hampered by low levels of exposure and by dosimetric uncertainties due to residential mobility. To address these limitations, the authors conducted a case-control study in a predominantly rural area of China with low mobility and high radon levels. Included were all lung cancer cases diagnosed between January 1994 and April 1998, aged 30–75 years, and residing in two prefectures. Randomly selected, population-based controls were matched on age, sex, and prefecture. Radon detectors were placed in all houses occupied for 2 or more years during the 5–30 years prior to enrollment. Measurements covered 77% of the possible exposure time. Mean radon concentrations were 230.4 Bq/m^3 for cases (n = 768) and 222.2 Bq/m^3 for controls (n = 1,659). Lung cancer risk increased with increasing radon level ($p < 0.001$). When a linear model was used, the excess odds ratios at 100 Bq/m^3 were 0.19 (95% confidence interval: 0.05, 0.47) for all subjects and 0.31 (95% confidence interval: 0.10, 0.81) for subjects for whom coverage of the exposure interval was 100%. Adjusting for exposure uncertainties increased estimates by 50%. Results support increased lung cancer risks with indoor radon exposures that may equal or exceed extrapolations based on miner data.