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RADON IMPLICATION IN LIFE AND EARTH SCIENCE: BĂIŢA-ŞTEI AREA AND PECENEAGA-CAMENA FAULT (ROMANIA)

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Abstract. Radon contribute in average with about 50% at the natural irradiation of people in the whole word and it is considered as responsible for a part of lung cancer death, being proved the second main cause for this illness after smoking. In other case, high soil radon anomalies are connected with the presence of tectonic faults or fissures and earthquakes. This work presents some methodological aspects of radon measurements, for indoor air and soil environment. The first part presents preliminary indoor radon exposure in Transilvania (Romania), in particular for Ştei-Băiţa radon-prone area, where special aspects were observed. Indoor radon survey shows that the annual mean for Ştei-Băiţa area (247 Bq·m^{-3}) is two times higher than the average value for Transilvania (124 Bq·m^{-3}). The second part presents preliminary results of soil radon measurements, in connection with the localisation and identification the direction of Peceneaga-Camena active fault. Measurement results were reproducible and have good representations, which indicated the existence and the presumed position of the fault zone orientated NW-SE. Measurement results were in the range from several to tens of kBq·m^{-3}, having distributions with maximum values up to 30 kBq·m^{-3}, obtained in immediate proximity of the fault.

Keywords: indoor radon, radon risk, prone area, Ştei-Băiţa, Peceneaga-Camena fault.

1. INTRODUCTION

The two isotopes of radon (222Rn and 220Rn) are the direct descendants of radium nuclides (226Ra and 224Ra). They are involved in many practical studies of medical, geological, climatic and other scientific aspects. Radon contribute in average with about 50% at the natural irradiation of people in the whole word and it is considered as responsible for a part of lung cancer death, being proved the second main cause for this illness after smoking (UNSCEAR, 2000). In radon risk areas (radon prone areas) this contribution is much higher until 90-95% growing the natural dose exposure of 5-10 times (Cosma et al., 2013 a). His contribution to the word mortality was estimated to be of 0.8-1.2 %, higher than other natural causes from fires, transport accidents or floods (UNSCEAR, 2000; Ghiassi-Nejad et al., 2002).

Radon anomalies are connected with some important geological features as presence of uranium and thorium agglomerations (Binns et al., 1998; Dahlkamp, 1993), faults or fissures evidence or volcanism manifestations (Papp et al., 2010). In many actual researches radon is considered as a possible precursor for earthquakes prediction (Chyi et al., 2010).

This paper presents a preliminary assessment of monitoring indoor radon exposure in Ştei-Băiţa radon-prone area, based on several measurements which are part of an extensive study in randomly selected houses carried out from 2000 to 2010. The second part of the present work is related on preliminary study on Peceneaga-Camena fault zone (Dobrogea-Romania). The aim of the study was the identification of location and direction of the Peceneaga-Camena tectonic fault, by the means of soil activity concentration measurements.

2. RADON IMPLICATION IN LIFE SCIENCE

The first part of the present paper represents a part of an extensive research of indoor radon exposure in Transylvania-Romania (Cosma et al., 2009). The most important high background radiation area in Transylvania was located in Ştei-Băiţa area (Bihor County), where the highest indoor radon concentrations, up to 4000 Bq·m^{-3} have been found (Sainz et al., 2009; Cucoş et al., 2012). Ştei-Băiţa area includes the town Ştei and few villages (Băiţa-Plai, Băiţa-Sat, Nucet, Fânaţe, Câmpani etc.) with a total of 16,000 inhabitants, located in the Bihor Mountains, in North-West of Romania, in the neighborhood of "Avram Iancu" and "Băiţa" uranium mines (see Fig. 1).

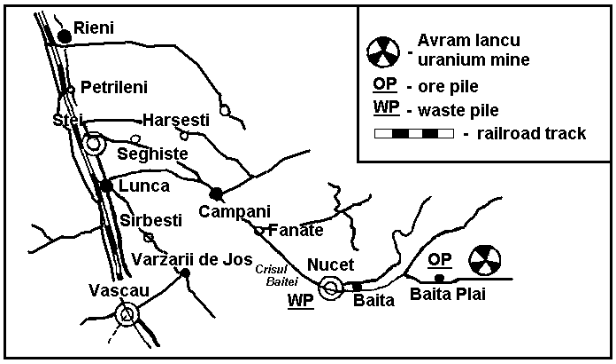

Figure 1. Ştei-Băiţa radon-prone area (Bihor County).

The main reasons for high indoor radon concentrations in this region are represented by the using of uranium tailings from uranium mines (operating in the period of 1950-1990) as building material. Also the soil under foundation with high radon concentration and soil gas permeability promotes the flow of radon-bearing gas from soil to indoor spaces. Most of these residential buildings were built using radioactive tailings. Similar problems are found in flats with the slab of the bottom floor in contact with the ground (Sainz et al., 2009; Cucos et al., 2012; Cosma et al., 2013 a).

2.1. Indoor radon measurements (experimental method)

Integrated radon measurements were performed in 335 dwellings of Ştei-Băiţa area using CR-39 track-etched detectors, according to the NRPB Measurements Protocol (Miles & Howarth, 2000). In order to evaluate average indoor radon concentrations, the detectors were exposed in the inhabited areas of dwellings, such as bedrooms and living-rooms, at a height of 1.0-1.5 m from the floor. After the exposure, the development process and the automatic reading of all detectors have been made in the Laboratory of Environmental Radioactivity, Babeş-Bolyai University, with the aid of the RadoSys-2000 equipment (Elektronika, Budapest, Hungary) operated in optimal conditions. The etching conditions were experimentally determined and consist in using a solution of 6.25 molar NaOH at a temperature of 90°C for an etching time of 4.5-6.0 hours (Cosma et al., 2009; Cosma et al., 2013 b).

The prolonged etching of CR-39 detectors showed that the background track density remains constant once they are fully etched, thus proving that the background is basically due to the surface defects. Radon concentration can be determined by counting the tracks in a given area. The individual error of radon measurements was estimated at less than 10% (Gillmore et al., 2005; Mishra et al., 2005). The accuracy of the detection system has been periodically checked by the successful participation in national and international radon intercomparison exercises with IFIN Institute of Bucharest, Radon Laboratory of Cantabria University, Spain, University of Veszprem, Hungary and National Institute of Radiological Sciences of Chiba, Japan, during the period 2007-2010 (Cosma et al., 2009; Janik et al., 2009).

2.2. Results and discussion regarding the residential radon

Based on an indoor radon survey performed in five Transylvanian counties (Cluj, Bihor, Bistrita, Sibiu and Alba from Romania) in the period of 2003-2008, a comparative result was established from Băiţa-Ştei area versus other counties from Transylvania. Results of this survey shows an annual average value for the Băiţa-Ştei area of **247 Bq·m^{-3}** (having the min-max range from 15 to 3998 Bq·m^{-3}, for 580 dwellings from the area). This annual mean is two times higher than the annual average value for the surveyed Transylvanian counties of **124 Bq·m^{-3}**, (having the same min-max range, for 1313 dwellings), and is also two times higher than the annual mean for Bihor county of **129 Bq·m^{-3}** (having min-max range from 25 to 1005 Bq·m^{-3}, for 209 dwellings in the county, without the results from Băiţa-Ştei area). These annual mean values for indoor radon concentration were calculated using a relationship between the measured values and the annual average (Cosma et al., 2009; Miles & Howarth, 2000).

Table 1. Summarized statistics for several indoor radon measurements in dwellings of Stei-Baita area (Bihor county, Transylvania, Romania), performed during 2000-2010.

Investigated villages	No. of houses	Annual mean ± S.D. [Bq·m^{-3}]	Rn range [Bq·m^{-3}]	Investigated season
Băiţa-Plai	23	578.0 ± 870.3	79.8 - 3653.4	All seasons
Băiţa-Sat	86	351.5 ± 566.7	10.2 - 3438.0	All seasons
Cîmpani	63	436.5 ± 576.7	20.3 - 3410.5	All seasons
Fînaţe	31	272.2 ± 245.7	48.7 - 1111.5	All seasons
Nucet	34	159.5 ± 269.8	12.2 - 1345.0	All seasons
Ştei	98	263.0 ± 353.5	10.0 - 1533.0	Winter-Summer
TOTAL	**335**	**343.5 ± 480.5**	**10.0 - 3653.4**	All seasons

In order to characterize the population exposure in Băiţa-Ştei area to radon levels inside dwellings, a number of about 335 integrated radon measurements were made in the area, during 2000-2010. This survey includes 6 localities, from Ştei to Băiţa-Plai (the last is closed to the area of Băiţa uranium mine). Summarized statistics of indoor radon concentration measurements for the area Băiţa-Ştei is presented in the table 1.

The annual mean values of indoor radon concentrations obtained from the measurements in dwellings of Ştei-Băiţa area are in the range from **10 to 3653 Bq·m^{-3}**, depending on the building material and soil characteristics under the building. Considering the seasonal corrections, the mean of the radon concentration in the area is **343.5 Bq·m^{-3}**, which is more than four times higher than the average indoor radon concentration of **82.5 Bq·m^{-3}** reported for Transylvania, before (Cosma et al., 2009; Sainz et al., 2009).

Indoor radon concentrations in monitored region are significantly higher than the recommended level of 100 Bq·m^{-3} for occupational and residential exposure of population (WHO, 2009). This is explained by the presence of radioactive tailings in building materials used in house construction, soil under construction with high levels of radon and high air permeability and the using of the local building material (sand, gravel) from Criş-Băiţa river (Cosma et al., 2013 a). Based of these results, the preliminary lung cancer risk for population in Ştei-Băiţa area was estimated. According to these data, 15 % of lung cancer deaths for life-time non-smokers can be attributed to radon exposure, while for smokers about 50 % of deaths due to this exposure were estimated (Truţă-Popa, et al., 2010). Dwellings having higher radon concentration than the recommended level of 200 Bq·m^{-3} for residential exposure to radon (i.e. houses from uranium area, radon prone area) can be mitigated applying passive and active mitigation technique in order to reducing indoor radon level (Nagy et al., 2011; Cosma et al., 2013 c).

3. RADON IMPLICATION IN EARTH SCIENCE

The second part of the study presents preliminary results of radon measurements at Peceneaga-Camena fault zone (Dobrogea). The aim of the study is to identify and locate the direction of the fault by soil radon measurements. Measurements were performed in a village (Fântâna Mare) which stands in the direction of the fault, and where currently is in progress a geodynamics research concerning the displacement of the fault (Besutiu & Zlagnean, 2009; Besutiu & Zlagnean, 2010).

The Peceneaga-Camena fault (PCF) is one of the most well known regional faults on the Romanian territory, with direction NW-SE, and represents the northern limit of the Moesian platform (Visarion & Beşuţiu, 2001). Several Romanian geophysicists consider PCF as the plate boundary between the Moesian Microplate and the East European Plate (Besutiu & Zlagnean, 2009). PCF crops out along its Dobrogean sector, separating the Upper Proterozoic Green Schist series of Central Dobrogea and the Palaeozoic-Mesozoic deposits of the North Dobrogea folded belt (see Fig. 2).

In order to clarify the current PCF geodynamic behaviour, the Institute of Geodynamics of the Romanian Academy started a geodetic experiment. On the PCF outcropping segment, at the Fântâna Mare (Baspunar) village a geodynamic observatory has been installed. In the name of Baspunar Experiment, the observatory has been equipped with two high accuracy Leica-TC-1201 total stations deployed on stable concrete pillars grounded in the Green Schist series of Central Dobrogea, pointing towards two laser reflectors installed on the other flank of PCF, at a distance of 300 m (on the school of the village) and, of 350 m (on the church of the village) respectively, on the

Triassic-Jurassic deposits of North Dobrogea. After about one year of monitoring, the preliminary remarks are that PCF undoubtedly behaves as an active strike-slip fault, and the average slip ranges between 1-6 mm/yr (Besutiu & Zlagnean, 2009; Besutiu & Zlagnean, 2010).

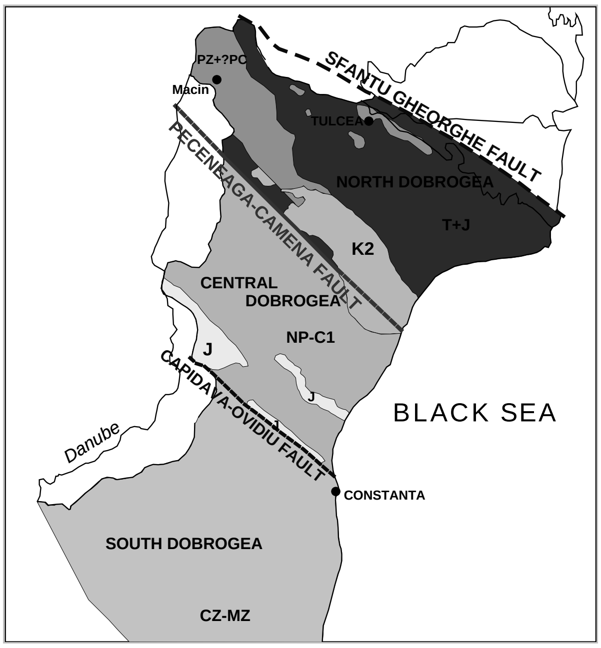

Figure 2. Tectonic sketch of Dobrogea showing P-C fault setting. (PZ+?PC-Paleozoic + Precambrian (Măcin unit); PZ-Paleozoic (Tulcea unit); T+J-Triasic+Jurasic (Tulcea unit); K2-Upper Cretaceous (Babadag); NP-C1-Neo-proterozoic-lower Cainozoic (Histria formation)).

3.1. Soil Radon measurements on the Peceneaga-Camena fault zone

The radon measurements on the Peceneaga-Camena Fault were performed in 2010 summer, in Fântâna-Mare village (Baspunar, Dobrogea), under dry conditions in the zone. The geo-coordinates of the village are: N: 44°51'42", E: 28°29'49", and the altitude between 130-170 m. According to the Baspunar experiment, the Peceneaga-Camena Fault crosses between the location of the mentioned geodynamics observatory and the two laser reflectors (mounted on the church and the school of the village).

The experimental method used in our study was based on the sampling of soil gas and measuring the 222Rn activity concentration of the samples, using a LUK3C radon detector, which was developed for radon measurements in soil gas. For the collection of soil gas, a special sampling probe was used (a steel pipe by the length of 1 m and diameter of 1 cm), which was inserted into the soil to a depth of 60 to 80 cm, in all cases. To create an active volume at the end of the probe in soil, it should remove a few cm. For soil gas sampling was used a Janet Syringe, with a volume of 150 mL (equal with the volume of the Lucas cell). The syringe was connected to the head of the sampling probe, and after minimum three subsequent extractions (to forcing soil gas and to avoid contamination by atmospheric air), the fourth syringe extraction of the soil gas sample was introduced into the detector cell, with the help of a preliminary vacuum technique (Barnet et al., 2008). The scheme for the soil gas sampling and its insertion into the Lucas cell of the LUK3C detector for radon concentration measurement have been found in Papp et al., 2010. The measurement method of the LUK3C detector was based on a scintillation technique with Lucas cells, by volume 145 mL. The efficiency of this technique was (2.2 counts/sec) at 1 Bq radon activity, deposited in the Lucas cell, when radon is in equilibrium with its daughters (Plch, 1997). The measurement principle is in separation of the counts come from the alpha decay of Rn, from the total incoming alpha counts (Rn+Tn). Since the half-life of Tn (55.6 sec) is much shorter than the half-life of Rn (3.82 days), Tn effectively decays in ~5 minutes. During this time, the detector does not measure, which called delay time. Following the delay time, the detector performed several countings that comes from the decay of the Rn atoms in the scintillation cell, and it finished when the statistic errors get under 5 %. Finally, the detector determines an average Rn concentration (corrected from the background of the cell). The total time of one measurement is no more than 10 minutes (Barnet et al., 2008).

3.2. Soil radon results and discussion on Peceneaga-Camena fault

Radon in soil measurements were performed in several places on the one side and other of the fault, by taking as reference points the observatory and the church and school in the village. The main selection criteria of measurement places were that they be within profiles to be normal to the assumed fault direction (NW-SE). The depth of sampling soil gas was 60 cm. In total 50 measurements of radon in soil were performed, grouped in 5 profiles. Because of field conditions, only a part of these measurements are relevant to perform representative distributions of radon concentrations. Thus, three sets of data were constructed, which form three well-defined profiles, each having 5 measurement points.

Table 2. Coordinates and altitude of the reference points (observatory, church and school), and the extremities of the three profiles (PA, PB and PC).

Places		N(gr,min,sec)	E(gr,min,sec)	Alt.(m)
observatory		44° 51' 32.7"	28° 29' 44.5"	154
church		44° 51' 42.9"	28° 29' 37.4"	142
school		44° 51' 41.2"	28° 29' 38.3"	141
Extremties of the profile PA	**PA1 (P26)**	44° 51' 42.4"	28° 29' 26.7"	148
	PA5 (P30)	44° 51' 39.2"	28° 29' 25.8"	146
Extremties of the profile PB	**PB1 (P9)**	44° 51' 39.8"	28° 29' 35.5"	141
	PB5 (P4)	44° 51' 34.8"	28° 29' 32.9"	159
Extremties of the profile PC	**PC1 (P14)**	44° 51' 39.7"	28° 29' 43.4"	132
	PC5 (P15)	44° 51' 34.1"	28° 29' 38.5"	148

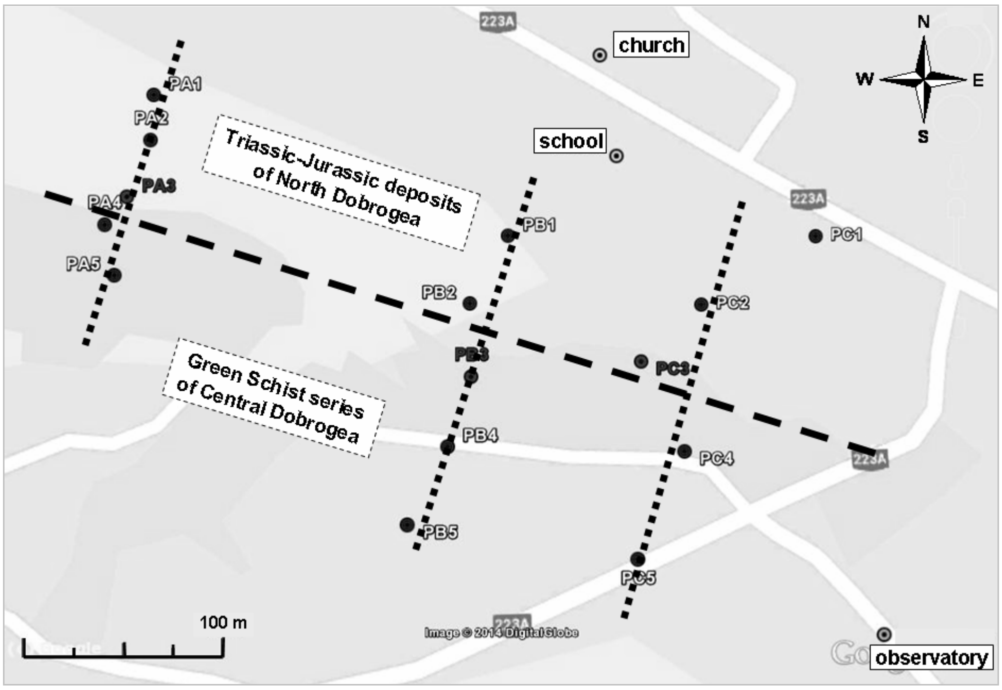

Figure 3. Location of measurement points along the profiles (PA, PB, and PC) with reference places, as observatory (located on the Green Schist part of Central Dobrogea), and church and school (located both in the Triasic-Jurasic part of North Dobrogea). The three dotted lines correspond to the measurement profiles, and the dashed line corresponds to the direction of the Peceneaga-Camena Fault (crosses near the points with radon concentration maxima).

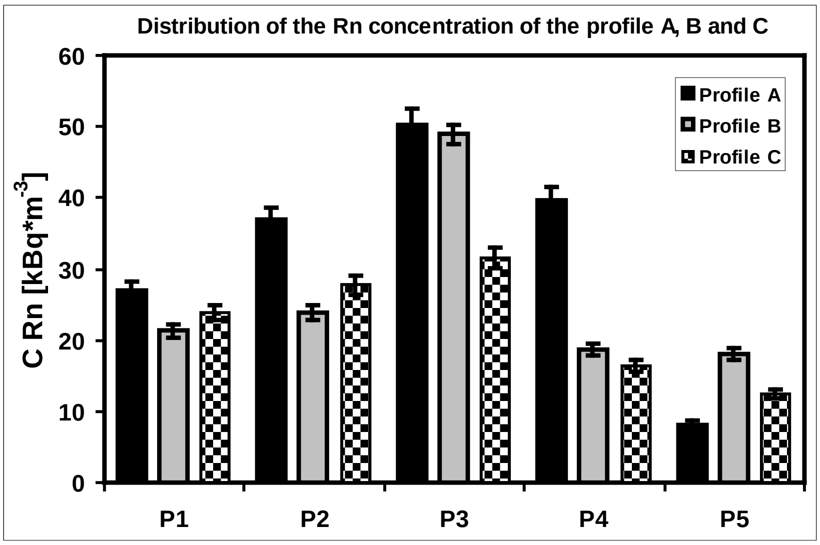

Figure 4. The distributions of the relevant radon concentrations for the three profiles PA, PB and PC, with errors.

The distances between the first and last points of the profiles was: 101 m for profile PA, 186 m for profile PB, and 205 m for profile PC, respectively. The geo-coordinates (latitude and longitude) of these measurement points (i.e. the three profiles), and of the reference places (observatory, church and school) recorded by the GPS, are presented in table 2 and are shown on a Google Earth Map (see figure 3, with the profiles and the direction of the fault).

Values of radon concentrations for all the 50 measurements lie within a wide range, between 8.0 and 50.3 kBq·m^{-3}. Values above 50 kBq·m^{-3} are radon anomalies, which are representative for fault zones, and radon risk areas. Representation of the measured concentration values for the three profiles was done in distributions with maxima, shown in figure 4.

Distributions of radon concentrations with a maximum were obtained, for the three profiles. For the profile PA, the maximum of concentration is 50.2 kBq·m^{-3}, for the profile PB is 48.9 kBq·m^{-3} and for the profile PC is of 31.5 kBq·m^{-3}, respectively. These distributions and maxima, shows that for the fault zone the radon concentrations in soil (at a depth of ~60 cm) are in the range of 20 to 50 kBq·m^{-3}. This seems to be the range for radon concentration values measured in soil on fault zones.

4. SUMMARY AND CONCLUSIONS

The paper presents a comparative survey of indoor radon performed in five counties in Transilvania (Romania) in a number of 1313 dwellings, during 2003-2008. Results of this study demonstrate that Baita-Stei area from Bihor county shows an average two times higher than the annual mean from Bihor county, without the results from Baita-Stei area (247 Bq·m^{-3}). An other survey of indoor radon was performed in several villages of Bihor-County (in the area of Baita-Stei, near the uranium mine), during 2000-2010. The results indicate an annual average value of indoor radon concentrations about 343.5 Bq·m^{-3}, and the percentage of dwellings with elevated radon concentrations above the exposure limit of 100 Bq·m^{-3} recommended by the authorities is approximately 70 %. Based on these results a high radon-lung cancer rate was estimated for the both smokers and non smokers. The critical situation requires that remedial actions to be applied, in the context in which until now in Romania has not implemented a regional programme or a national strategy regarding radon mitigation.

The soil radon measurements carried on Peceneaga-Camena Fault (Dobrogea, Romania) were reproducible and have good representations, which results indicated the existence and the presumed position of the fault zone orientated NW-SE. Measurement results shows normal distributions of the studied profiles, with a maximum of radon concentrations, having values higher than 30 kBq·m^{-3}. These distributions are also consistent with the hypothesis that the fault crosses through the points with maximum values of radon concentrations.

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REFERENCES

Barnet, I., Pacherová, P., Neznal, M., Neznal, M., 2008. *Radon in geological environment - Czech experience*. Special Papers No.19, Czech Geological Survey. Prague, pp.25-30.

Besutiu, L., Zlagnean, L., 2009. *Watching structural and geodynamic features of a plate-boundary: Peceneaga - Camena Fault*. Geophysical Research Abstracts, EGU General Assembly 2009-12023, Vienna, 11.

Besutiu, L., Zlagnean, L., 2010. *Monitoring dynamics of an active plate-boundary: Peceneaga-Camena Fault*. Geophysical Research Abstracts, EGU General Assembly 2010-1514, Vienna, 12.

Binns, D. A. C., Figueiredo, N., Melo, V. P., Gouvea, V. A., 1998. *Radon-222 measurements in a uranium-prospecting area in Brazil*, Journal of Environmental Radioactivity, 38 (2), 249-254.

Chyi, L. L., Quick, T. J., Yang, T. F., Chen, C. H., 2010. *The experimental investigation of soil gas radon migration mechanisms and its implication in earthquake forecast*. Geofluids, **10**(4), 556-563.

Cosma, C., Szacsvai, K., Dinu, A., Ciorba, D., Dicu, T., Suciu, L., 2009. *Preliminary integrated indoor radon measurements in Transylvania (Romania)*. Isotopes in Environmental and Health Studies, **45**(3), 259-268.

Cosma, C., Cucoş (Dinu), A., Papp, B., Begy, R. & Sainz, C., 2013a. *Soil and building material as main sources of indoor radon in Băiţa-Ştei radon prone area (Romania)*. Journal of Environmental Radioactivity, 116, 174-179.

Cosma, C., Cucoş (Dinu), A., Papp, B., Moldovan, M., Begy, R., Dicu, T., Niţă, D.C., Burghele, B.D., Fulea, D., Cîndea, C., Rusu (Dumitru), O., Maloş, C., Suciu, L., Banciu, G. & Sainz, C., 2013b. *Radon measurements and radon remediation in Băiţa-Ştei prone area.* Carpathian Journal of Earth and Environmental Sciences, **8** (2), 191-199.

Cosma C., Cucoş A., Papp B., Begy R., Dicu T., Moldovan M., Truţă A., Niţă D., Burghele B., Suciu L. & Sainz C., 2013c, *Radon and remediation measures near Băiţa-Ştei old uranium mine (Romania).* Acta Geophysica, **61**(4), 859-875.

Cucoş (Dinu), A., Cosma, C., Dicu, T., Begy R., Moldovan, M., Papp, B., Niţă, D., Burghele, B. & Sainz, C., 2012. *Thorough investigations on indoor radon in Băiţa radon-prone area (Romania).* Science of the Total Environment, 431 (1), 78-83.

Dahlkamp, F. J., 1993. *Uranium ore deposits*. Springer-Verlag, Berlin, pp. 460.

Ghiassi-Nejad, M., Mortazavi, S. M. J., Cameron, J. R., Niroomand-rad, A., Karam, P. A., 2002. *Very High Background Radiation Areas of Ramsar, Iran: Preliminary Biological Studies*. Health Physics, 82(1): 87-93.

Gillmore, G. K., Phillips, P. S., Denman, A. R., 2005. *The effects of geology and the impact of seasonal correction factors on indoor radon levels: a case study approach*. Journal of Environmental Radioactivity, 84 (3), 469-479.

Janik, M., Tokonami, S., Kovács, T., Kávási, N., Kranrod, C., Sorimachi, A., Takahashi, H., Miyahara, N., Ishikawa, T., 2009. *International intercomparisons of integrating radon detectors in the NIRS radon chamber*. Applied Radiation and Isotopes, 67 (9), 1691-1696.

Miles, J.C.H., Howarth, C.B., 2000. *Validation scheme for laboratories making measurements of radon in dwelling: 2000*. Revision NRPB-M1140 (National Radiological Protection Board, Chilton, 2000), p.11.

Mishra, R., Orlando, C., Tommasino, L., Tonnarini, S., Trevisi, R., 2005. *A better understanding of the background of CR-39 detectors*. Radiation Measurements, 40 (2-6), 325-328.

Nagy, H.É., Breitner, D., Horváth, Á., Szabó, Cs., 2011. *Study of a passive radon mitigation process and indoor radon concentration's time dependence after mitigation*. Carpathian Journal of Earth and Environmental Sciences, **6**(2), 143-149.

Papp, B., Szakács, A., Néda, T., Papp, Sz., Cosma, C., 2010. *Soil radon and thoron studies near the mofettes at Harghita Bai (Romania) and their relation to the field location of fault zones*. Geofluids, **10**(4), 586-593.

Plch, J., 1997. *Manual for Operating LUK 3C Device*, Jiri Plch, M. Eng. SMM, Prague.

Sainz, C., Dinu, A., Dicu, T., Szacsvai, K., Cosma, C., Quindós, L. S., 2009. *Comparative risk assessment of residential radon exposures in two radon-prone areas, Ştei (Romania) and Torrelodones (Spain)*. Science of The Total Environment, **407**(15), 4452-4460.

Truţă-Popa, L. A., Dinu, A., Dicu, T., Szacsvai, K., Cosma, C., Hofmann, W., 2010. *Preliminary lung cancer risk assessment of exposure to radon progeny for Transylvania, Romania*. Health Physics, **99**(3), 301-307.

UNSCEAR, 2000, *Sources and effects of ionizing radiation*, Report to the General Assembly of the United Nations with Scientific Annex B, Exposures from natural radiation sources, New York, pp. 96-105.

Visarion, M., Besutiu, L., 2001. *Fracturi transcrustale pe teritoriul Romaniei (Trans-crustal faults on the Romanian territory).* in Studii şi cercetări în geofizică, Ed. Bucuresti, 39, p.15-33, (in Romanian).

WHO, 2009. *Handbook on indoor radon, a public health perspective*. World Health Organization, edited by Hajo Zeeb, and Ferid Shannoun, pp.110.

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