ВИВЧЕННЯ ДОСВІДУ КАРТУВАННЯ РАДОНОНЕБЕЗПЕЧНИХ ТЕРИТОРІЙ У ПІЛОТНОМУ САВРАНСЬКОМУ РАЙОНІ ОДЕСЬКОЇ ОБЛАСТІ УКРАЇНИ

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LESSONS LEARNED FROM THE RADON RISK MAPPING IN A PILOT SAVRAN DISTRICT OF ODESSA REGION, UKRAINE

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ВИВЧЕННЯ ДОСВІДУ КАРТУВАННЯ РАДОНОНЕБЕЗПЕЧНИХ ТЕРИТОРІЙ У ПІЛОТНОМУ САВРАНСЬКОМУ РАЙОНІ ОДЕСЬКОЇ ОБЛАСТІ УКРАЇНИ
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У статті наведено результати наукового проекту з картування радонових ризиків, які проведено у 2010-2011 роках у Савранському районі Одеської області. Метод, який використовувався під час досліджень, розроблено шведськими фахівцями у 1980-ті роки та широко використовується нині в європейських країнах [1]. Польові дослідження були проведені в усіх населених пунктах Савранського району і передбачали гамма-спектрометрію урану, торію і калію у ґрунтах та еманометричні вимірювання радону у повітрі ґрунтів. Результати вимірювань є репрезентативними для території України.
Ключові слова: радон, картування радонового ризику.

ИЗУЧЕНИЕ ОПЫТА КАРТИРОВАНИЯ РАДОНООПАСНЫХ ТЕРРИТОРИЙ В ПИЛОТНОМ САВРАНСКОМ РАЙОНЕ ОДЕССКОЙ ОБЛАСТИ УКРАИНЫ
Герман О. ("Ваттенфалл", Швеция)
В статье приведены результаты научного проекта по картированию радоновых рисков, проведенного в 2010-2011 годах в Савранском районе Одесской области. Метод, который применялся в ходе исследования, разработан шведскими специалистами в 1980-е годы и широко используется в некоторых европейских странах сегодня [1]. Полевые исследования были проведены во всех населенных пунктах Савранского района и включали гамма-спектрометрию урана, тория и калия в грунтах, а также эманометрические измерения радона в почвенном воздухе. Результаты измерений являются репрезентативными для территории Украины.
Ключевые слова: радон, картирование радонового риска.

Radon-222 is formed at the decay of radium-226. Radium-226 is in turn formed in the decay series starting with uranium-238. Uranium is found in all soils and rocks in small quantities, although the amount varies between different rock- and soil types. Even though there is an obvious relation between uranium (radium) and radon the amount of radon atoms formed that can reach the pore space is dependent on type of mineral, cracks in minerals and water content. For soils the grain size, porosity and weathering together with the water content is most important [1].

Radon is a highly radioactive and carcinogenic inert gas that may cause mutations in the cells of organisms if inhaled or ingested. Radon is next to smoking the most important cause of lung cancer in humans [2].

The average concentration of uranium in the Earth's crust is 3 mg/kg. There is always enough radon in the ground to cause enhanced radon levels indoors, if the basement holds cracks or openings. Radon from the ground is the most common cause of increased radon levels in buildings.

There are three sources of indoor radon: water, building material and ground under the house.

The household water will influence indoor radon concentration if the water is pumped into the house directly from the ground water source, with high radon concentration in it. If municipal water is used in the household the risk of elevated radon concentration decreases dramatically due to the long distances of water bearing pipes and the water processing at the water stations. Radon will either decay to very low concentrations or will be blown away during the processing.

As for the building materials these are to be produced from the radium rich material to be able to cause radon trouble, as it was the case in Sweden during the early 70-ies of the last century. For the Ukrainian situation no such materials have been used in the country due to rather strict regulatory control of building material. There are radiological limits set by the regulatory documents which were introduced early during the Soviet Era.

Thus the major source of the indoor radon in Ukraine is the ground under the building. Almost all buildings are affected by radon that leaks in from the underlying ground and then mixes with the indoor air. The radon gas is either transported together with soil gas, in which case the

LESSONS LEARNED FROM THE RADON RISK MAPPING IN A PILOT SAVRAN DISTRICT OF ODESSA REGION, UKRAINE

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This article presents the results of the radon risk mapping carried out in 2010 and 2011 in Odessa Savran district. The method applied in the work was developed by the Swedish radon experts in the 80-ies and is widely used in several European countries in our days. The radon risk assessment is done based on the number of geological, geomorphologic and hydrological data and measurements [1].

Field investigations have been performed in the Savran district with measurements in all villages. Gamma spectrometers were used to measure the uranium, thorium and potassium concentration in soils and emanometers were used to measure radon in soil gas. The results of the measurements are considered representative for Ukrainian soils.

Keywords: radon, radon risk mapping.

soil gas is actively driven into the building through cracks, joints and holes in the foundation by the stack effect created by the pressure difference between indoor and outdoor atmosphere, or by the diffusion through the upper soil layer and the floor/concrete slab laying on the ground or above the crawl space. In most buildings the in-leakage of radon only results in low radon indoor concentrations, <50 $Bq.m^{-3}$, but if the volume of soil air that leaks into the building is larger than 1-5 m^3/h or the radon concentration in the soil air is high, >50000 $Bq.m^{-3}$, this often results in indoor radon concentrations higher than 200 $Bq.m^{-3}$ [3-5].

As radon transported from the ground is the main cause to indoor radon knowledge on the concentration of radioactive elements, primarily uranium, in rocks and soils forms the main source for information on radon prone regions, areas and sites.

Methodology. Mapping of radon potential areas is done to help and ensure that occupants of new and existing buildings are protected from the harmful effects of radon. The maps can be used both to take the proper precautions for new buildings as well as effectively searching for houses with enhanced radon levels among the existing buildings. Even with a very detailed mapping it is important to realize that every house is unique and radon levels can vary widely between neighbouring houses because of the construction of the house and local geology. The radon potential maps shall be seen as the name implies: they indicate the radon *potential* of an area [3, 6, 7].

Literature study shows that many countries have mapped the radon risks but the methods used differ. While some countries solely base their radon maps on radon measurements indoors most countries also take into account where the radon comes from i.e. the geology [4, 6, 8-12].

For the geological based radon potential maps information is gathered of soil and bedrock types, content of uranium and radon in soils and bedrock, permeability and moisture of the soils Airborne measurements can be very useful as a tool in mapping and finding radon prone areas. There is a close correlation between airborne and ground radiometric measurements. Measurements of radon in houses and in drinking water can also be valuable. Some countries like Great Britain, Czech Republic and USA, also include indoor radon concentrations [4, 7, 11-13].

Field measurements. Two field expeditions were performed in the Savran district with the purpose of measuring radon in ground and collection of the input information necessary for the radon risk map of the district.

The first field work was carried out in October 2010 and the second part of the work was carried out in May 2011.

Measurements of the concentration of uranium, thorium and potassium in soil were determined by gamma ray spectrometer GR-130 on the ground surface and in ca 0,8 m dug holes. The result of a measurement in a hole must be multiplied with 0,6 to get the real concentrations. The concentration of radon-222 in soil gas was sampled and analysed in the field with an emanometer of the type Gammadata MARKUS-10. The samples were taken within 1-3 m from each other at one locality. The field survey measurements were carried out with equipment belonging to SGU and SSM (Portable Gamma Ray Spectrometer GR-130 from Exploranium — 2 sets and MARKUS 10-3 sets in 2010 and 4 sets in 2011. The gamma spectrometers are calibrated every year.

Positioning was gathered (in longitude and latitude) with GPS for all measuring points. Other information that was noted in the measuring protocol at each point was weather conditions, soil moisture at the measurement depth, grain combination and soil type.

Classification. With the results from the different measurements together with the geological information the radon potential of an area can be classified. Traditionally the ground has been classified as high, normal and low radon ground. In table 1 and 2 are shown the values used when classifying the ground according to Clavensjo & Akerblom [5].

Note that the radon concentration in the soil gas is nearly always high enough to give too high radon level indoors if enough soil gas can leak in. It is therefore now recommended that the class *low radon ground is avoided.*

Geological setting of the Savran district. The Savran district is situated in the northern most part of Odessa Oblast on the Ukrainian flatland. The flatland is in part undulating and with a number of valleys and rivers where the Savran river is the largest running in an east-west direction [15-18].

Table 1

High radon ground [1]

Bedrock or soil type	Ra-226 ($Bq.kg^{-1}$)	Radon in soil ($kBq.m^{-3}$)
Bedrock surface	> 200	
Fill of blasted rock	> 80	
Gravel, coarse sand, silt and till	> 50	> 50
Silt	> 70	> 60
Clay, clayey till	> 100	> 100

Along the Savran river there are a sandy soils with little fine material. Sandy soils were also found along some smaller rivers but with minor depth and purity.

Away from rivers the soil is generally clayey to silty clayey. On agricultural lands there is a dark brown to black chernozem in the top layer. The depth of the chernozem varies between 0,2 m to more than 2 m. In the large grass covered step areas the top soil is reddish brown silty clayey soils with the chernozem more or less missing. Some excavations in alluvial sand and gravel with weathered surfaces could be studied in some gravel pits.

The bedrock was encountered at two places in the district, at a tributary to the Savran river, a gneiss with pegmatitic weins and a rock pit with a migmatite east of Savran. The bedrock was also seen just north of the Savran district with the graphite mine at Zavaille.

During the winter 2010-2011 87 radon measurements were performed indoors in private houses, preschools and schools in 10 villages in the Savran district.

During the field work 10 soil samples were taken for analyses of the granulometric composition and organic content to compare to literature data [15-17]. The analyses were done by SLU, Dept. Of Soil and Environment, Uppsala, during the winter 2011-2012. In total 218 measurements have been done in most villages within the Savran district.

Results. All results of the field measurements are presented were interpreted and a radon risk map was developed.

The sites for field measurements were concentrated to the villages of the district and not directed to different types of geology or soil types. This means that a geological based radon potential map will not be presented. The planned map will instead be based on the results of measurements for each village.

Within the Savran district two soil types could be distinguished with marked different uranium and radon concentrations. The sandy soils especially along the Savran river have very low concentrations of the radon and low concentration of uranium and thorium while the large areas with silty and clayey chernozems have marked higher concentrations of uranium and radon.

In a few localities the uranium concentration was higher on top of the soil than at a depth of 80 cm. These localities were on agricultural fields so the explanation is probably the use of a phosphoritic fertiliser containing uranium.

The 10 granulometric analyses showed a clay content of around 40% and a humus content up to 4,7% in dark chernozem samples. To make radon measurements in clayey and silty soils with the MARKUS-10 is often difficult because the soil is too wet or compact. In some localities this was the case and radon results are therefore lacking for these. Despite the high silt and clay content in many soils radon measurements could be done. The high humus content and the grainy structure of the chernozem facilitated the radon transport.

The uranium concentration in silt and clay is quite similar and at normal levels at 3-4 ppm. The two soil types was not so easy to separate in the field because of the black topsoil. In sand the uranium concentration were only between 1 ppm and 2 ppm.

Table 2

Low radon ground [1]

Bedrock or soil type	Ra-226 (Bq.kg^{-1})	Radon in soil (kBq.m^{-3})
Bedrock surface	< 60	
Blasted rock, gravel, sand, coarse silt, till	< 25	< 10
Silt	< 50	< 20
Clay	< 80	< 60

Table 3

Radon (kBq/m^3) in soil gas in clay, silt and sand

	Clay	Silt	Sand
Mean arithmetic	34,1	39,5	7,7
Mean geometric	31,5	38	7,0
Max	79	108	23

Table 4

Results from gamma spectrometer measurements in different soil types, depth 70-80 cm

	No	Mean a	Mean g	Max	Min
Clay					
K, %	41	2,9	2,9	3,9	1,4
U, ppm	41	4,2	3,9	9,3	2,5
Th, ppm	41	18,0	18,1	22,5	12,3
Ra, Bq/kg	41	51,5	47,7	115,4	30,6
Silt					
K, %	27	2,8	3,0	3,5	1,0
U, ppm	26	3,8	3,9	5,4	0,8
Th, ppm	27	17,5	18,9	22,1	4,7
Ra, Bq/kg	26	46,5	48,6	67,3	10,5
Sand					
K, %	20	1,6	1,6	2,7	1,0
U, ppm	19	1,6	1,3	4,1	0,4
Th, ppm	20	7,3	6,4	17,0	2,2
Ra, Bq/kg	19	19,8	16,4	50,8	5,1

Indoor measurements. The indoor measurements were performed in the Savran district in January — February 2011. There is a difference between the two data sets for soil type which is to be expected. The village with the lowest radon concentrations indoors is Vilshanka (mean 100 Bq.m^{-3}) which is situated along the Savran river. The soil in Vilshanka is sandy. The results of measurements of radon and uranium in soil also show low concentrations.

In the other villages the indoor radon concentration is generally higher but with larger variations. Baksha has the highest meang radon concentration with Bq.m^{-3} and also the highest measured radon concentration indoors with 903 Bq.m^{-3}. The soil in the Baksha area is dominated by chernozem and clay.

CONCLUSIONS AND RECOMMENDATIONS. The project has showed that clayey black chernozem soils in the Savran district have moderate concentrations of radon, uranium and thorium. Despite this the radon levels indoors are elevated above 200 Bq.m^{-3} in many houses. The reason for this is:

1. The construction of buildings with sparse insulation towards the ground.

2. The chernozem is somewhat astonishing, apparently permeable for the transport of radon gas.

The sandy soils have low concentrations of the radioactive elements and many houses have low radon concentration indoors in these areas.

To discriminate the different clayey or silty soil types and if there are any differences in the concentration of the radioactive elements more field investigations are necessary. Soil maps with detailed soil information can be useful in the continued work.

Continued investigations of radon concentration indoors are firstly recommended to concentrate to the clayey chernozem areas.

Table 5

Relation between gamma spectrometer measurements on the ground surface ($_s$) and in a dug pit ($_p$) ca 70-80 cm depth at the same locality

	№	Mean$_a$	Mean$_g$	Max	Min
K_s/K_p (%)	87	0,6	0,5	1,2	0,4
U_s/U_p (ppm)	85	0,7	0,5	1,9	0,2
Th_s/Th_p (ppm)	85	0,6	0,5	1,2	0,0

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