Radon hazard in Moscow, Russia

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Abstract: Publicity in modern cities concerning the serious geo-environmental problem of radon (^{222}Rn), in inhabited and industrial premises, is ever increasing. High concentrations of radon in premises are generally connected with the constant decay of radon (alpha decay ^{226}Ra) from soils and rocks. The problem is revealing the degree of the potential radon hazard and the geological structure that allows radon to enter premises. It is vital that during the construction of a building the appropriate protection against radon is undertaken. It is possible to discriminate two types of hazardous area: 1) mountain belts with signs of ancient and young platforms where vertical migration of radon occurs through cracks. Here radon can rise to the ground surface from great depth with ascending streams of groundwater or in ascending discontinuities as gas. In such areas radon hazard sites are identified with zones of tectonic fractures. 2) Plates of ancient and young platforms where the movement of radon occurs mainly in a horizontal direction with artesian and subsoil waters.

Our research shows that in these areas radon moves to the surface of the ground only from the rocks lying above the level of groundwater. The radon formed in deeper structures, is taken up by streams of groundwater, is transported, and then decays before reaching the ground surface. Here radon hazard territories are to a lesser degree connected with tectonic events, but are mainly determined by concentrations of ^{226}Ra in overlying soils. Moscow is located within the limits of the Russian plate and so affected by the second type of radon area. In Moscow high values of density of a stream of radon (more than 80 mBq/m2sek) were measured for sites where (in daytime) clay outcrops with concentration of ^{226}Ra 25-45 Bq/kg. On the sites composed sandy materials, with concentrations of ^{226}Ra 5-20 Bq/kg, values of radon do not exceed 20-50 mBq/m2sek. Thus, in territory of Moscow the sites combined from a surface clay are potentially radon hazard.

Résumé: Dans les villes d'aujourd'hui le problème géoécologique grave est celui de l'irradiation par le radon (Rn) des gens dans les maisons. Détection du risque de radon potentiel des territoires, compte tenu de leur structure géologique, permet de prévoir les mesures pour protéger les bâtiments contre radon lors de la construction. A l'échelle régionale on peut distinguer deux types des terrains. 1) Les zones de montagne et les panneaux des platforms où prédomine la migration verticale de Rn aux zones de la fissurité. 2) Les plaques des platforms où le déplacement de Rn a lieu principalement dans une direction horizontale aux eaux souterraines. Dans ces zones radon arrive à la surface terrestre seulement des roches qui gisent au-dessus du niveau des eaux souterraines. En ces lieux le risque de radon des territoires est au minimum lié aux accidents tectoniques mais il est déterminé par la concentration de ^{226}Ra dans les sols superficielles. Sur le territoire de Moscou, qui est de deuxième type, les zones portant du risque de radon sont celles où près de la superficie gisent les argiles avec la concentration de ^{226}Ra dépassant 30-45 Bq/kg.

Keywords: engineering geology, environmental geology, radioactive tracers, geochemistry, geological hazards, geology of cities.

INTRODUCTION

In modern cities radon irradiation (^{222}Rn) of populated and industrial areas forms a serious geo-ecological problem. Scientists have begun paying attention to the problem of radon hazard in cities. The first systematic data on radon concentrations within dwellings of Sweden and the USA appeared only in the late 1970s. At that time it became clear that exposure to radon irradiation in houses posed no less threat to health than, for example, professional exposure of miners to irradiation in uranium mines. In Russia the radiation safety of professional workers has always been a matter of great attention and concern, but the danger for city-dwellers was only realized in the early 1990s, when there appeared new publications of the International Committee for Radiation Protection at the UNO. During the 1990s a systematic collection of material was conducted on radon concentration in dwelling houses in Russia. This work made clear that about 1 million Russian inhabitants are exposed to radon at doses of over 10 mSv/year; 68 % of them are exposed to doses exceeding 20 mSv/year (the dose limit for professionals). So the exposure of population to radon irradiation in some regions of the country exceeds the dose received by workers in radiation-dangerous industries (data by A. M. Marennyi et al. 1999). The irradiation level in such areas is elevated or high, and requires safety measures to reduce radon concentration in the air of dwelling buildings. High radon concentration in buildings is usually connected with emergence of radon from the building foundation soil, where radon is constantly forming from the alpha decay of radium (^{226}Ra). It is important to reveal the extent of areas at risk to radon, which will allow the planning of suitable safety measures during building construction (Krisyuk 1989).

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Potential danger of radon is defined firstly by the geological structure of the territory and by the concentration of ^{226}Ra in rocks and soils. On a global scale we can identify two fundamentally different types of territory.

1) Mountain belts and areas of ancient and young platforms, where vertical migration of radon along fractures is dominant. In hydro-geological terms, these territories are blocks where fluids migration is confined to residual soil and zones of deep joint fissures. Here radon can rise to the earth surface from depth together with upward streams of groundwater or in upward gas streams. In such areas radon-dangerous zones are confined mostly to geo-dynamically active zones of tectonic fractures. The conditions of radon migration in blocks of rocks have been thoroughly studied during gas and geochemical surveys in researching the tectonic structure of territories, and to find uranium deposits. The principles of radon vertical migration, in areas of tectonic fractures with upward streams of groundwater and in gas jets, are described in numerous works by G.F. Novikov (1989), N.A. Titaeva (2000), V.I. Utkin (2000) and other researchers.

2) Plates of ancient and young platforms, where radon movement is mainly horizontal together with groundwater. Ancient and young platforms in hydro-geological terms are artesian basins, where groundwater streams are confined to horizontal water-permeable beds, separated by retaining clay levels. For these territories there is typical de-watering of the rock mass, except near-surface zones of suspended water, low velocity groundwater flows and poorly developed tectonically active water-permeable zones. Our research has shown that, in these areas, radon comes to the earth surface only from layers above the subterranean groundwater level. Radon formed in deeper structures is taken by streams of groundwater, and is transported with them, and decays before reaching the earth surface. Here the danger of radon is less connected with tectonic disturbances, but is mainly determined by concentration of ^{226}Ra in near-surface soils. Moscow is situated within the Russian plate, i.e. it belongs to the second territory type.

A comparison of radon flux density measurements, conducted on original ground and on construction footings and pits, shows that the main source of radon emergence into the atmosphere is soils of the zone of suspended water occurring between the original ground and the subterranean water levels. Analysis of the spatial changeability of radon flux density shows that there is a statistically relevant difference between its values in areas of sandy and clay materials. The radon flux from clay materials is much higher than that from sandy materials (the Table 1). It is connected to considerably higher radium (^{226}Ra) concentrations (of parent one when compared to radon) in clay grounds.

Table 1. Density values for a stream of radon from a day surface in the Moscow area.

Parameter	**Range**	
Type (structure) of material	clay	sand
Quantity of the investigated sites	556	649
arithmetic mean, mBq/m^{2}sek	20.5	38.6
standard deviation, mBq/m^{2}sek	11.8	34.4
geometric mean, mBq/m^{2}sek	18.0	29.3
geometric standard deviation, mBq/m^{2}sek	1.7	2.1
Minimum, mBq/m^{2}sek	5.0	4.0
Maximum, mBq/m^{2}sek	72.0	264.0

The Moscow area has been divided according to the nature of radon sources (Figure 1) into areas formed from the surface mainly by: 1) sandy and 2) clay materials. For division into districts "The Scheme of Engineering-Geological Division Into Districts of Territory of Moscow" has been used (Golodkovskaya & Lebedeva 1997). The first area type includes the valley of river Moscow and its tributaries, and also fluvial-glacial plain in the northeastern part of the city, where mostly sands and clay sands with radium concentration of 5-15 Bq/kg lie near the surface. The second type of areas is widespread in the southern, southwestern, and northern parts of the city, where glacial loams and fluvial-glacial sands are overlain by clays, of up to 2–6 m in thickness. Radium concentration in clay materials are generally between 15 and 30 Bq/kg.

The statistical data manipulation according to areas (the Table 1) shows that the distribution of radon flux density (RFD) values within each type is accidental and can be described by the logarithmically normal law (Figure 2). Actual values of RFD do not go beyond the range of "the three sigmas" for logarithmically normal distribution. It means that local high values of radon fluxes are accidental background fluctuations, are not abnormal, and are not connected with large non-uniform soil masses (regional zones of hyperpermeability, considerable radon content fluctuations). The last conclusion is of particular importance since, until now, high values of RFD have been considered abnormal, and this encouraged the search of sources of radon hyper-emission, which were not previously defined.

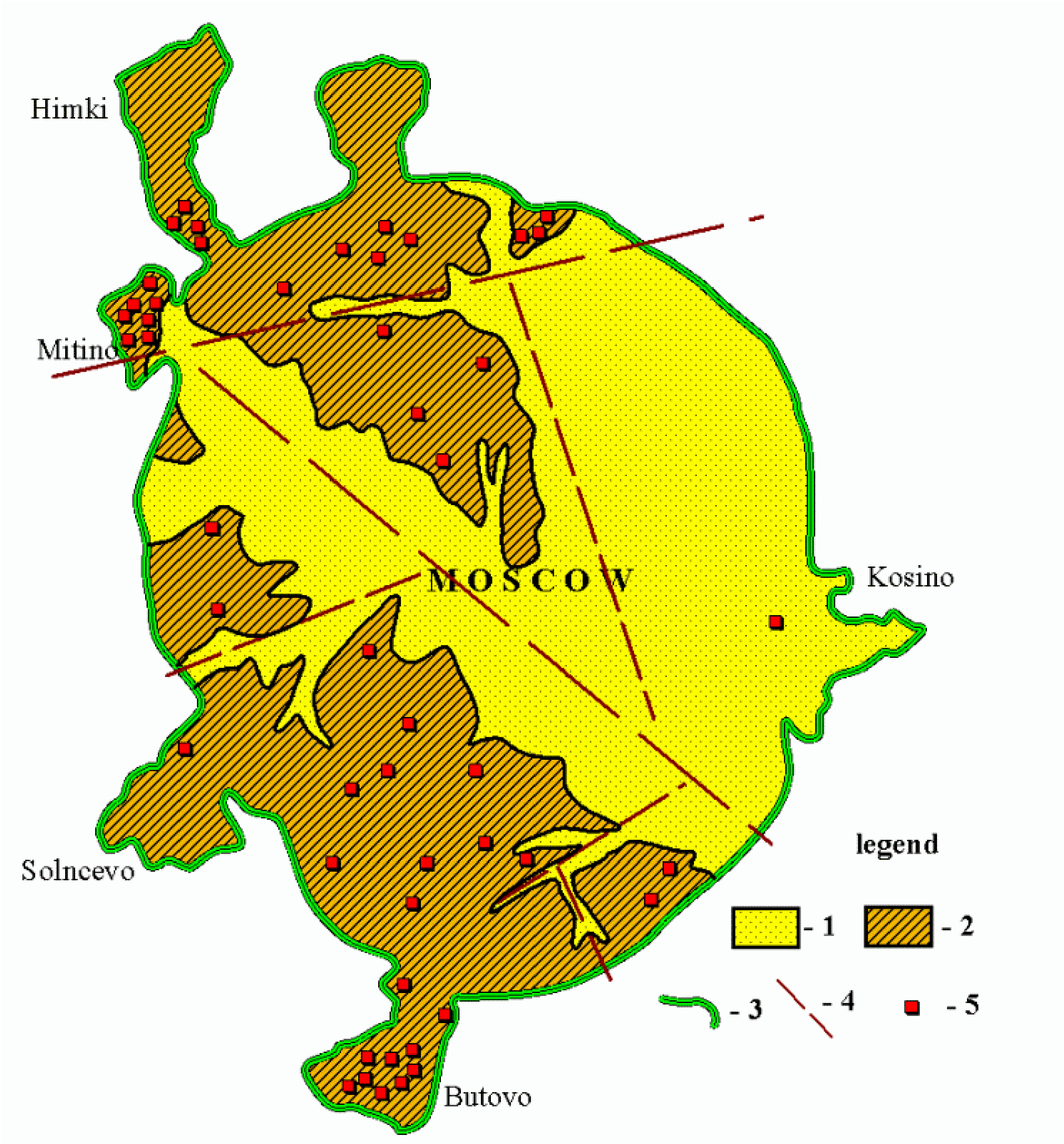

Figure 1. The scheme of division into districts of territory of Moscow according to the nature of radon sources: 1- areas where sandy materials exist at the surface (concentration ^{226}Ra 5-20 Bq/kg); 2- areas where the surface is clay (concentration ^{226}Ra 25-45 Bq/kg); 3- border of city of Moscow; 4- axes of zones of tectonic breaks; 5- sites within the limits of which average value of radon flux density exceeds 80 mBq/m2sek.

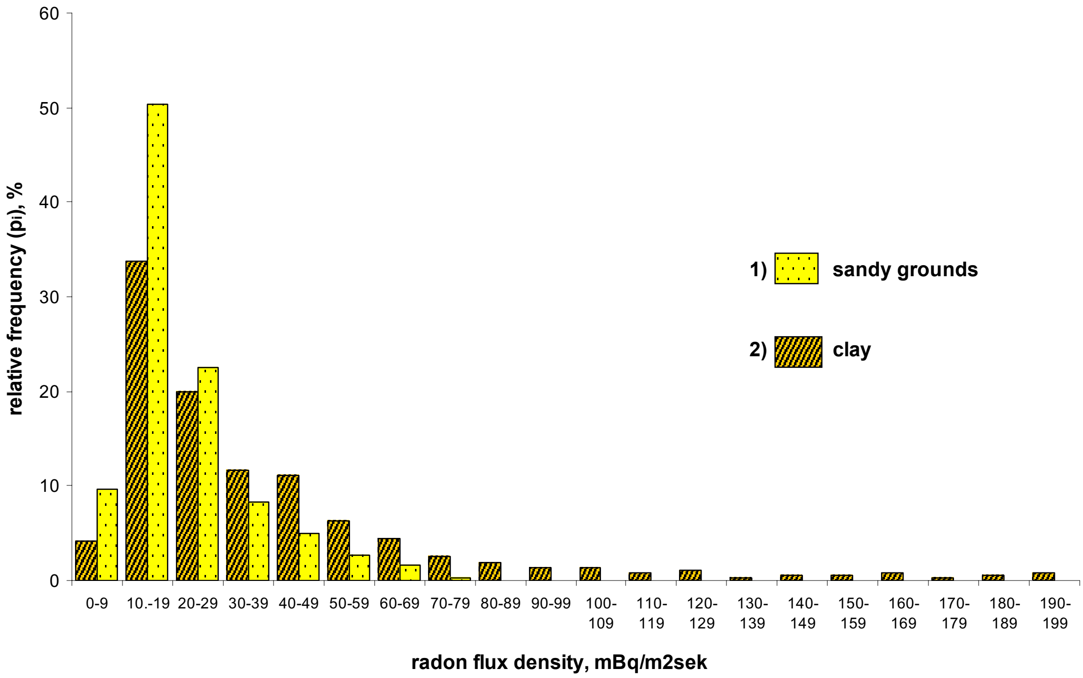

Figure 2. Distribution of radon flux density from a day surface in territory of Moscow: 1) sites where sandy materials exist at the surface (concentration ^{226}Ra 5-20 Bq/kg); 2) sites where the surface is clay (concentration ^{226}Ra 25-45 Bq/kg).

The logarithmically normal distribution of RFD values means that the RFD values spread, in soils of the same type, is determined by local microfractures in their near-surface structure, which apparently play the role of permeable radon-transferring channels, since fracture permeability of clays is several times more than undisturbed clay grounds permeability. Radon-dangerous areas are identified when there is a combination of relatively high (over 25 Bq/kg) specific activity of radium (^{226}Ra) in near-surface soils and permeable disturbances in their structure.

Fracturing of near-surface materials can be linked to endogenous tectonic or rotary zones (geo-dynamically active), as well as with exogenous and anthropogenic processes. N. M. Haime (1998) points out that deformations are greatly influenced by exogenous shearing in loose materials and connected with seasonal fluctuations of temperature and humidity in the plate groundmass, as well as by anthropogenic reasons: building construction, transport, vibration during machines and mechanisms running, formation of subterranean waters depression cones, ground works and change of ground stress condition. Distribution according to exogenous and anthropogenic ground fracturing within a large city is incidental, and clearly determines the observed accidental distribution of RFD values within areas formed by grounds of the same type.

In addition, near endogenous active zones there is an increase in the offset, variety and amplitude in near-surface materials. Therefore these zones can influence the radon field of grounds. So during large-scale works in the Chertanovo region in south-west of Moscow conducted by specialists of Institute of Geoecology RAN and the Moscow State University of Geological Exploration there has revealed a connection between activity concentration of radon in ground air and active structural elements (Makarov et al. 2003). The received data do not permit differential analysis of the connection between the intensivity of radon exhalation from grounds mass and geo-dynamically active zones. The comparison of the spatial distribution, on a city-wide scale, of potential radon-dangerous areas (RFD over 80 mBq/m^{2}s) with largest flexure-fracture zones on the territory of Moscow, shows that there is no correlation between them. At the same time one can clearly see that radon-dangerous zones are confined to areas characterized by clay outcrop (Figure 1, 2, the Table 1). In areas of sandy material outcrop, where there is not enough radium, radon-dangerous zones (RFD > 80 mBq/m^{2}s) are not registered, regardless of whether there are geo-dynamically active zones or not. So the main factor determining radon flux density is apparently the lithological analysis of near-surface materials. This work is ongoing and the influence of geo-dynamically active zones on radon flux density as zones with overlapping of endogenous, exogenous, and man-caused fractures of the near-surface grounds mass is a matter of active research.

In conclusion, it has been found that within the ancient platforms, to which the Moscow territory belongs, radon entering the atmosphere forms initially from the surface ground layer of the suspended water zone. The danger of radon for territories is determined by attributes of this layer – radium concentration, macro- and micro-fractures in the structure (various genesis) and by their water level.

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REFERENCES

GOLODKOVSKAYA, G.A. & LEBEDEVA, N.I. 1997. Engineering-geological division into districts for construction. *Moscow. Geology and city.* "Moscovskie uchebniki I kartolitographiya", Moscow, **5**(10), 208-221 (in Russian).

HAIME, N.M. 2000. Quantitative estimation of tectonic displacement in platform regions. *Environmental Geosciences,* **2**, 107-115 (in Russian).

KRISYUK, E. M. 1989. *Radiation background of living quarters.* Energoatomizdat, Moscow,117 p. (in Russian).

MAKAROV, V.I., BABAK, V.I., BONDARENKO, V.M., DEMIN N.V. 2003. Influence of structurally-geological features on distribution of concentration of radon in soils and concentration of radon in cellars of residential buildings (on an example of municipal area Chertanovo of Moscow). *Environmental Geosciences,* **2,** 223-236 (in Russian).

MARENNYI, A.M., SAVKIN, M.N., & SHINKAREV S.N. 1999. Model for an estimation of a collective dose of an irradiation of the population of Russia from radon. *News of radiation measurements,* **4**, 4-11 (in Russian).

NOVIKOV, G.F. 1989. *Radiometric methods of exploring*. Nedra, Leningrad, 407 p. . (in Russian).

TITAEVA N.A. 2000. *Nuclear geochemistry.* Publishers of MSU*,* Moscow, 366 p. (in Russian).

UTKIN V.I. 2000. Problem of radon in ecology. *Soros educational journal***,** **6**, 73-80 (in Russian).