2012

RAD

The First International Conference on Radiation and Dosimetry in Various Fields of Research

APRIL 25 - 27, 2012
FACULTY OF ELECTRONIC ENGINEERING | NIŠ | SERBIA

PROCEEDINGS

MMXII

RAD 2012

POPULATION DOSES FROM TERRESTRIAL GAMMA EXPOSURE IN BELGRADE (SERBIA) AND THEIR RELATION TO GEOLOGICAL SETTING

Lj. Janković-Mandić[1], R. Dragović[2], M. Djolić[1], A. Onjia[1], S. Dragović[3]

[1]University of Belgrade, Vinča Institute of Nuclear Sciences, P.O. Box 522, Belgrade
[2]University of Niš, Faculty of Science and Mathematics, Višegradska 33, Niš
[3]University of Belgrade, Institute for the Application of Nuclear Energy, Banatska 31b, Belgrade

Abstract. *Terrestrial radiation exposure emitted from naturally occurring radionuclides, such as 40K and radionuclides from the 238U and 232Th series and their decay products represent the main external source of irradation to human body. The purpose of this study was to provide the assessment of the doses from terrestrial exposure of population in Belgrade. The gamma dose rate, annual effective doses and external hazard indexes due to terrestrial natural occurring radionuclides (226Ra, 232Th, 40K) were calculated based on their activities in soil samples in Belgrade determined by gamma-ray spectrometry. The mean value of the total absorbed gamma dose rate outdoors due to terrestrial radionuclides for Belgrade was 59 nGy/h which is close to the worldwide average value (58 nGy/h). The values of the gamma dose rate varied among sampling locations as a consequence of different geological formations in the investigated area. The mean value of annual effective dose of 73 μSv was significantly lower than the maximum allowed dose of 1 mSv for the population and was consistent with the worldwide average value. The mean value of external hazard index was found to be 0.28. The results of this assessment study pointed out that there is no significant radiation risk to the population of Belgrade due to terrestrial exposure to radiation from natural sources outdoors.*

Key words: *radium, thorium, potassium, exposure, lithology.*

1. Introduction

Assessment of the radiation doses in humans from natural sources is of special importance because natural radiation is the largest contributor to the collective dose received by the world population. The knowledge of the doses from natural background is necessary as a basis for comparison with man-made sources of exposure. Moreover, owing to the large variability of doses from natural sources of radiation, some individual doses may be high enough to obligate the introduction of remedial measures. Many radionuclides exist naturally at trace levels in various soil and rock formations. Particular interest is being focused on the external exposure due to gamma radiation emitted by naturally occurring radionuclides. The significant sources of this external exposure are the ^{238}U decay chain, the ^{232}Th decay chain and the ^{40}K. This exposure depends primarily on the geological and geographical conditions and, a significant part, is delivered outdoors [1].

The aim of this work to determine the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil samples collected across the city of Belgrade, the capital of Serbia, using gamma ray spectrometry and use the results to calculate absorbed gamma dose rate in air, annual effective dose equivalent and external hazard index Belgrade is expected to change from being a city to a conurbation in the near future and baseline data of this type will be of importance in the assessments of population exposure.

2. Materials and methods

The city of Belgrade is located in the northern part of Serbia. It spreads over area of about 1000 km^2 and has a population of approximately 1.8 million, i.e. about 20% of total population of Serbia.

The samples of undisturbed soils were collected from 70 locations of Belgrade during 2006-2010. A total of 230 samples were collected. From each location, 3-4 subsamples were collected by template method [2], up to depth of 10 cm. Samples were dried at 105 °C to a constant weight and then homogenized. The homogenized samples were placed in 1L Marinelli beakers. The beakers were sealed hermetically and kept aside for about a month to ensure equilibrium between ^{226}Ra and its daughters before being taken for gamma spectrometric analysis.

The measurements were performed using HPGe gamma-ray spectrometer ORTEC-AMETEK (34%

relative efficiency and 1.85 keV FWHM for ^{60}Co at 1.33 MeV, 8192 channels) shielded with 10 cm lead internally lined with 2 mm copper foil. The weight of each sample was approximately 1 kg. The activity of each sample was measured for 60 ks. A mixed calibration source MBSS 2 from Czech Metrological Institute, was used for efficiency calibration in the same geometry as the measured samples. For the purpose of quality assurance, independent checks on calibration were performed using two standard reference materials from International Atomic Energy Agency (IAEA-385) and Environmental Measurement Laboratory United States Department of Energy (QAP-9803). The activity of ^{226}Ra was evaluated from the gamma ray of 609.3 keV of ^{214}Bi peak and 351.9 keV of ^{214}Pb, while 911.2 and 969.1 keV gamma-ray lines emitted by ^{228}Ac and 238.6 keV emitted by ^{212}Pb was used to determine ^{232}Th. The activity of ^{40}K was determined using its 1460.8 keV gamma-ray line.

Gamma Vision 32 was used to process the spectra obtained [3]. Statistical evaluation of obtained results was performed using statistical package SPSS 10.0 for Windows [4].

2.1. Absorbed gamma dose rate

The external gamma dose rate in the air at 1 m above ground level was calculated from the measured activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil assuming that other radionuclides, such as ^{137}Cs, ^{90}Sr and the ^{235}U series can be neglected as they contribute very little to the total dose from environmental background [5,6,7]. The calculation were performed according to the following equation [1]:

$$D = 0.462ARa + 0.604ATh + 0.042AK \quad (1)$$

where A_{Ra}, A_{Th}, and A_K are activity concentrations (Bq kg^{-1}) of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

2.2. Annual effective dose equivalent

In order to estimate the annual effective doses, one must take into account the conversion coefficient from absorbed dose in air to effective dose and the indoor occupancy factor. Using the dose conversion factor of 0.7 Sv Gy^{-1} and occupancy factor of 0.2 adopted by UNSCEAR (2000) the annual effective dose equivalent (AEDE) was calculated as follows [1]:

$$AEDE = D \times 8760 \times 0.7 \times 0.2 \quad (2)$$

2.3. External hazard index

The external hazard index H_{ex} provides a useful guideline for regulating the safety standards on radiation protection for the general public. It was calculated by using the equation [8]:

$$H_{ex} = A_{Ra}/370 + A_{Th}/259 + A_K/4810 \quad (3)$$

where A_{Ra},A_{Th},,A_K are activity concentrations (Bq kg^{-1}) of ^{226}Ra, ^{232}Th and ^{40}K respectively, in soil samples. The value of this index must be less than unity to keep the radiation hazard insignificant, i.e. to keep the radium equivalent activity and annual dose under the permissible limits of 370 Bq kg^{-1} and 1 mSv, respectively [9].

3. Results and discussion

Descriptive statistics for activity concentrations of primordial radionuclides in soil samples collected in Belgrade area is presented in Table 1.

Table 1 Descriptive statistics of activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K for all analyzed soil samples

Parameter	Activity concentration (Bq kg^{-1})		
	^{226}Ra	^{232}Th	^{40}K
Range	43	53	520
Mean	33	38	500
Median	35	39	500
St. deviation	8	9	100
Minimum	12	11	280
Maximum	55	64	800

It can be seen that activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, ranged from 12 to 55 Bq kg^{-1}, from 11 to 64 Bq kg^{-1} and from 280 to 800 Bq kg^{-1}, respectively. The mean activity concentration for ^{226}Ra of 33 Bq kg^{-1} was close to the world average value of 32 Bq kg^{-1}, that of ^{232}Th 38 Bq kg^{-1} was about 18% lower than the world average value, while mean activity concentration of ^{40}K 504 Bq kg^{-1} was 18% higher than world average value. The analyzed radionuclides showed a range of concentrations, as a consequence of the variety of lithological components in the investigated area. The most of sampling locations are situated on terrains of the southern rim of Panonian area and the northern parts of Sumadian mesozoic joist. There are two structural floors in tectonics of Belgrade area. The first one is composed of jurassic and cretaceous sediments and magmatic products. The parts of mesozoic joist on west are composed of flysh sediments of upper cretaceous series, which are covered by neogen sediments with horizontal stratification important for the development of pedological cover. The second structural floor is composed of neogen sediments. More than 70% of the territory of Belgrade is covered by quaternary deposits of alluvial lake, alluvial marsh, alluvial, delluvial, delluvial, delluvial-prolluvial, prolluvial and eolic sediments. Near the Sava and Danube rivers, alluvial sediments are deposited, and in the area of Zemun and Bezanija, loess is predominant [10]. Such a geological composition, together with the expressed structural formations and different terrain elevation, causes differences in concentration of analyzed radionuclides in soils.

Descriptive statistics for the total absorbed gamma dose rates (D), annual effective dose equivalent (AEDE) and external hazard index (Hex**)** are presented in Table 2.

Table 2 Descriptive statistics of total gamma dose rate due to ^{226}Ra, ^{232}Th and 40K, annual effective dose equivalent and external hazard index

Parameter	D (nGy h^{-1})	AEDE (μSv y^{-1})	H_{ex}
Range	65	79	0.28
Mean	59	73	0.28
Median	59	74	0.27
St. deviation	12	14	0.06
Minimum	25	31	0.16
Maximum	90	110	0.44

The values of total gamma dose rates varied between 25 and 90 nGy h^{-1} with the mean value of 59 nGy h^{-1}. According to UNSCEAR (2000) [1], the dose rate in air outdoors from terrestrial gamma rays in normal circumstances is approximately 60 nGy h^{-1} and the national average ranges from 1 to 1100 nGy h^{-1}. The mean value of D for soils analyzed in this study is close to the world average value. The contribution to the total absorbed gamma dose rate by ^{226}Ra, ^{232}Th and ^{40}K was 25%, 39% and 36%, respectively. The contribution of each radionuclide to the total dose depends primarily on soil type and geological background of each investigated location.

The values of annual effective dose equivalent (AEDE) for different locations Belgrade ranged from 31 to 110 μSv y^{-1} with mean value of 73 μSv y^{-1}, which is much below the maximum permissible dose of 1 mSv y^{-1} recommended by the ICRP for members of the public [9] and also less than the average external gamma dose of 0.48 mSv y^{-1} from natural radiation sources of terrestrial origin assessed by UNSCEAR (2000) [1].

The range and mean values of absorbed gamma dose rate due to ^{226}Ra, ^{232}Th and ^{40}K obtained for Belgrade are compared with values reported for cities worldwide (Table 3).

City	D (nGy h^{-1})
Alkharje, Saudi Arabia [11]	24 (15-30)
Bangalore,India [12]	117 (61-202)
Belgrade, Serbia, *present study*	*59 (25-90)*
Faisalabad, Pakistan [13]	73 (62-79)
Ibadan, Nigeria [14]	32 (17-42)
Istanbul, Turkey [15]	49 (15-71)
Santana do Matos, Brazil [16]	107 (32-330)
Tripoli, Libya [17]	23 (20-24)
Windhoek, Namibia [18]	56 (41-70)
Zacatecas, Guadalupe,Mexico [19]	45 (28-67)
Zahedan,Iran [20]	158 (16-300)

Table 3. Absorbed gamma dose rates in cities from different parts of the world compared with that obtained in present study

It can be seen that the mean value of gamma dose rate observed in the present study (59 nGy h^{-1}) lies within the reported values. It is comparable with those reported for the cities of Zacatecas, Mexico [19] (45 nGy h^{-1}), Windhoek, Namibia [18] (56 nGy h^{-1}) and Istanbul, Turkey [15] (49 nGy h^{-1}). The value obtained in the present study is 2.6-fold lower than that assessed by Hosseini (2007) for Zahedan, Iran [20] (158 nGy h^{-1}).

However, it is about 2.5-fold higher than gamma dose rates reported for Tripoli, Libya [17] (23 nGy h^{-1}) and Alkharje, Saudi Arabia [11] (24 nGy h^{-1}). These differences in terrestrial radioactivity, and the associated external exposure due to gamma radiation, are caused by geological and geographical specifities of investigated areas. The high gamma dose rates reported for Teheran could be explained by its geological composition which includes metaluminous to weakly peraluminous rocks, corresponding to

magnetite- and ilmenite-bearing granitoids, ranging from diorites to granites [21]. The mean value of external hazard index was found to be 0.28. The results of this assessment study pointed out that there is no significant radiation risk to the population of Belgrade due to terrestrial exposure to radiation from natural sources outdoors

The results of this study are useful as a data baseline for preparing a radiological map of the studied area as well as for enrichment of the worlds data bank. Before more definite conclusions of hazards of population exposure to natural radionuclides and drawn, an extended and more systematic survey of the area in needed.

Acknowledgement: This work was supported by the Ministry of Education and Science of the Republic of Serbia (Project No. III 43009).

References

1. United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR), Exposure from Natural Radiation Sources, New York: United Nations, 2000.
2. International Atomic Energy Agency, Soil sampling for environmental contaminants, IAEA-TECDOC-1415, 2004.
3. ORTEC, Gamma Vision 32, Gamma-Ray Spectrum Analysis and MCA Emulation, Version 5.3. Oak Ridge, USA, 2001.
4. SPSS Inc. Statistical Package for the Social Sciences (SPSS) v. 10.0, Chicago, Illinois, http://www.spss.com. 1999.
5. D.C. Kocher, A.L. Sjoreen, Dose-rate conversion factors for external exposure to photon emmiters in soil. Health Phys, vol. 48, 1985, pp. 193-205.
6. P. Jacob, H.G. Paretzke, H. Rosenbaum, and M. Zankl, Effective dose equivalents for photon exposure from plane sources on the ground, Radiat. Prot. Dosim. vol.14, 1986, pp 299-300.
7. K.C. Leung, S.Y. Lau, and C.B. Poon, Gamma radiation dose from radionuclides in Hong Kong soil, J. Environ. Radioact. vol. 11, 1990, pp. 279-290.
8. J. Beretka, and P.J. Mathew, Natural radioactivity of Australian building materials, industrial wastes and byproducts, Health Phys. vol 48, 1995, pp. 87-95.
9. International Commission on Radiological Protection. Recommendations of the International Commission on Radiological Protection, ICRP Publication 60, Ann. ICRP 21, Oxford: Pergamon, 1990.
10. M. Komatina, and S.M. Komatina, Hydrogeological factors in the solving of geotechnical problems in an urban environment: A case study for Belgrade, Yugoslavia. In: Chilton, J. (Ed.), Groundwater in the Urban Environment, Selected City Profiles. (Rotterdam: Balkema) 1999, pp. 317-322.
11. H. Orabi, A. Al-Shareaif, and M. El Galefi, Gamma-ray measurements of naturally occuring radioactive

sample from Alkharje City, J. Radioanal. Nucl. Chem., vol 269, 2006, pp. 99-102.
12. N.G. Shiva Prasad, N. Nagaiah, G.V. Ashok, and N. Karunakara, Concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the soils of Bangalore region, India, Health Phys., vol. 94, 2008, pp.264-271.
13. M. Tufail, N. Akhtar, and M. Waqas, Measurement of terrestrial radiation for assessment of gamma dose from cultivated and barren saline soils of Faisalabad in Pakistan. Radiat. Meas.
14. N.N. Jibiri, and O.S. Bankole, Soil radioactivity and radiation absorbed dose rates at roadsides in high-traffic density areas in Ibadan metropolis, southwestern Nigeria, Radiat. Prot. Dosim.,vol 118, 2006, pp. 453-45841, 443-451 (2006).
15. G. Karahan, and A. Bayulken, Assessment of gamma dose rates around Istanbul (Turkey). J. Environ. Radioact., vol. 47,2000, pp. 213-221.
16. A. Malanca, and L. Gaidolfi, Natural radiation exposure in a municipality of the Brazilian Sertao, Environ. Intern. vol 22, 1996, pp.213-217.
17. M.A. Shenber, Measurement of natural radioactivity levels in soil in Tripoli, Appl. Radiat. Isot. vol 48, 1997, pp.147-148.
18. J.A. Oyedele, Assessment of the natural radioactivity in the soils of Windhoek city, Namibia, Southern Africa, Radiat. Prot. Dosim., vol 121, 2006, pp. 337-340.
19. F. Mireles, J.I. Davila, L.L. Quirino, J.F. Lugo, J.L. Pinedo and C. Rios, Natural soil gamma radioactivity levels and resultant gamma dose rate in the cities of Zacatecas and Guadalupe, Zacatecas, Mexico, Health Phys,. vol 84, 2003, pp. 368-372.
20. S.A. Hosseini, Naturally occuring radioactivity in the city and across near by cities in Iran, J. Appl. Sci., vol 7, 2007, pp.3091-3095.
21. M. Sadeghian, J.L. Bouchez, A. Nedelec, R. Siqueira and M.V. Valizadeh, The granite pluton of Zahedan (SE Iran): a petrological and magnetic fabric study of a syntectonic sill emplaced in a transtensional setting, J. Asian Earth Sci. vol 25, 2005, pp.301-327.