NATURAL IONIZING RADIATION AND HUMAN HEALTH IN SERBIA

by

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This paper provides information about potential effects of natural ionizing radiation on general population health. Natural radionuclides are particularly stressed, as well as health effects of high and lower doses. Radio-ecological areals have been presented for Serbia, while radiation risk has been assessed for the population of Serbia according to census years.

Key words: natural ionizing radiation, health, Serbia

INTRODUCTION

Life on Earth is constantly exposed to natural ionizing radiation effects. Since this radiation had been present before life even existed on Earth, living world has relatively adapted to the existing level of radiation, so it is assumed that such radiation does not have any negative impacts. Moreover, there are spots of the Earth where radiation is higher than average, but its impact on population health is even positive (*e. g.* spas with radioactive water springs). On the other hand, there are places, *i. e.*, parts of the Earth's surface, with considerably high overall natural ionizing radiation where its impact on human health is negative.

Radiological load of the population primarily occurs due to the presence of gamma radiation field in the environment, and is dominantly conditioned by the levels of cosmic and terrestrial radiation, and geographic position.

Sources of ionizing radiation are present everywhere in the environment and according to their genesis they may be divided into natural (natural radioactivity) and anthropogenic ones (generated, artificial radioactivity). According to Jović [1], about 80% of total annual radiation originates from natural sources, while approximately 20% originates from artificial radiation sources. Natural sources include natural earth radionuclides, cosmogenic radionuclides, and cosmic radiation; anthropogenic sources include radioactive rainfall, and medical, technogenic, and radioactive waste. The mechanism of ionizing radiation effect for all the mentioned groups may be external (radiation to organism) and internal (radiation within an organism via food chain), so overall radiation load may be external and internal [2].

The intensity of cosmic radiation grows with the increase of altitude and latitude. The equivalent annual dose of terrestrial radiation at the sea level amounts to 0.3 mSv. Bearing in mind that the equivalent annual dose of terrestrial radiation in the areas with average radiation load amounts to approximately 0.8 mSv, and that it may go above 1 mSv in the areas with the increased concentrations of radionuclides (for the areas with ^{238}U and ^{232}Th 1.37 mSv on average, while for ^{40}K it is 0.3 mSv), the mean annual natural radiation ranges between 1 and 2 mSv, depending on the dwelling place. Extreme annual terrestrial radiation is recorded in India, state of Kerala, and it amounts to 11 mSv [3, 4] (tab. 1).

NATUAL RADIONUCLIDES

Among the natural radionuclides, natural earth radionuclides have the greatest impact on human health, both in terms of overall radiation and in terms of high local radiation doses. Based on the research done so far, natural radioactivity of lithosphere (biosphere) amounts to one-fourth of the total basic radiation load of all living creatures [5].

Most commonly, natural earth radionuclides have internal effects, *i. e.*, they enter the human body through inhalation or ingestion (through drinking wa-

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Table 1. Integrated radiological load originating from different sources

	Natural radiological load [mSv]		Artificial radiological load [mSv]	
	Terrestrial radiation	Cosmic radiation	Radioactivity of air	Radioactive rainfall
Mean value for the areas with the average radiological load	0.8	0.3	0.02	0.03
Excessively high value for certain areas (country)	10 India Brazil Gabon	3 Peru	0.2 England (smog)	
Annual dose	0.51	0.32		

Source: Petrović, Mitrović [13]

ter and food of plant or animal origin), and they radiate human cells internally, which leads to considerable radiation load of human population in certain areas.

About 80 radioactive isotopes have been recognized in nature so far. The most common natural radionuclide in lithosphere is ^{87}Rb, followed by ^{232}Th, ^{40}K. and ^{238}U. However, the highest risk to human health is posed by ^{238}U and its descendants ^{226}Ra and ^{222}Rn, with the half-lives of 1600 years and 3.824 days [6].

Depending on their geo-chemical characteristics, radionuclides are concentrated and dispersed through geochemical processes in various parts of the environment (stones and ores on the Earth surface, soil, water, air, vegetation).

In addition to natural radionuclides, there are also artificial radioisotopes in nature, which are widely spread in the world, where their circulation in soil is monitored by the intensity of erosion supported by water and wind. In addition to their impact on human health, knowing the specific activity of natural radionuclides and artificial isotopes enables us to assume vertical distribution through soil, as well as their circulation in the environment [7].

Table 2. Distribution of radionuclides in human body

Organ	Introduction path	Radionuclides	
		Natural	Artificial
Lungs	Inhalation of gases and aerosols	^{222}Rn, ^{210}Po, ^{85}Kr, ^{130}Xe	^{218}Po, ^{210}Pb, ^{239}Pu, ^{240}Pu
Bones	Ingestion (food and water)	^{226}Ra, ^{228}Ra, ^{210}Pb	^{90}Sr, ^{239}Pu, ^{240}Pu
Thyroid gland	Ingestion (food and water)	^{226}Ra, ^{228}Ra	^{129}J, ^{131}J
Kidneys	Ingestion (food and water)	^{230}Th, ^{232}Th, ^{235}U, ^{238}U	^{239}Pu, ^{240}Pu
Liver	Ingestion (food and water)	^{210}Po	^{198}Au, ^{239}Pu, ^{240}Pu

Source: Jović, Jovanović [1]

Presence of natural radionuclides in the environment is most commonly low. However, depending on geochemical cycles of certain elements, these radionuclides may be concentrated locally in a part of the environment up the level which presents a risk to human health [6]. Moreover, the risk to human health depends on the local concentration of radionuclides, but it depends significantly more on its biological adoptability (tab. 2).

There used to be a notion that human being had adapted to the natural gamma radiation field in the environment over the time (terrestrial and cosmic one), taking into account that radionuclides had been present in the environment since the formation of the Earth, *i. e*., since the time when Cosmos and chemical elements came into existence. Over the time, the intensity of natural radiation has decreased, so that the values of this radiation today are up to three times smaller than in the geological past. However, later investigations(1) have shown that areas with higher concentration of natural radionuclides in soil, stones, water, and air are characterized by the increased number of innate deformations and organic illnesses and higher mortality rate (especially among children), thus slowing down natural accretion [8].

A human may be irradiated by natural radionuclides via construction materials of natural origin, via food (ingestion) and drinking water, and a human body itself contains radioactive elements, among which ^{40}K, as an integral part of the blood, is the dominating one [9, 10].

The total radiation of population includes significant annual dose of radiation originating from construction material, taking into account the constant exposure of population to this type of radiation in the environment(2). For example, the annual radiation dose for wood, gypsum, and artificial materials amounts to 0 mSv, for tiles and concrete 0.1 mSv to 0.2 mSv, for stone and arti-

(1) New data related to this area have been obtained through researches implemented by numerous international organizations, such as World Health Organization (WHO), International Commission on Radiological Protection (ICRP), International Atomic Energy Agency (IAEA), United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR), Commission for Biological Effects of Ionizing Radiation (BEIR) and others.

(2) In order to assess radiological risk in use of certain construction material, Ra_{eq} (effective specific activity) is used as a measure, which takes into account the activity of three most important radioactive elements: ^{226}Ra, ^{232}Th, and ^{40}K, expressed in Bq/kg. Radiological risk is calculated by the means of the following formula: $Ra_{eq} = A(\text{Ra}) + 1{,}43A(\text{Th}) + 0{,}077\,A(\text{K})$ [11]. Thereby, Ra_{eq} = = 150 Bq/kg for cement originating from Serbia, 193 Bq/kg for bricks, and 1,229 Bq/kg for phosphorous gypsum [9].
In order to assess the *intensity of the absorbed dose of gamma radiation* (D) in closed areas depending on the specific activity of natural radionuclides from construction materials, different mathematical models can be applied, among which Zastanjny's equation is most commonly used: $D = 49{,}5\,A(\text{Ra}) + 65{,}5\,A(\text{Th}) + 4{,}5\,A(\text{K})10^{-4}$ mGy per year. Applying this equation, it has been calculated that the residents of Serbia who spend time in brick buildings absorb a dose of gamma radiation of 0.978 mGy per year, while those who live in concrete buildings absorb 0.431 mGy per year [11].

ficial gypsum 0.2 mSv to 0.8 mSv, while for slag and pumice 0.8 mSv to 1.7 mSv [1]. The results of a research conducted by the UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) show that out of the total annual equivalent dose originating from natural radiation sources, which amounts to 2.4 mSv per inhabitant, most of it ($^2/_3$ to ¾, sometimes even up to 80%), is found in residential buildings [5, 11, 12].

RADIOECOLOGICAL AREALS IN SERBIA

The existence of different levels of natural radionuclides in certain geo-space biosphere has conditioned the definition of a term *radio-ecological areal (REA)*, whereat radiological load of certain biocenoses depends basically on a biotope. To this end, analogously to the existence of bio-geo-chemical provinces and bio-geo-chemical endemisms, the existence of *radio-geo-chemical endemisms (RGCE)* would be logical. Although scientists still argue about the term of radio-geo-chemical endemism, based on a number of literature sources, it may be concluded that *there is a significant correlation between the level of background radiation and mortality occurring due to malignant diseases* [(3)] [13].

Based on the investigations conducted in Serbia between 1970 and 1975, the existence of 11 radio-ecological areals with different intensities of exposure doses of gamma environmental radiation (0.2-2.0 pC kgs) was established [13]. Geographic distribution of REA in Serbia, depending on the intensity of the exposure dose of gamma radiation, is provided in fig. 1.

Background radiation of biosphere[(4)] is a value which changes in time. Changes in the intensity of the exposure dose in the field of gamma environmental radiation occurred in Serbia as well, so the distribution and size of certain REA differ according to the situation that was in place during the 1970s. These changes occurred primarily due to anthropogenic impacts, including the large impact of Chernobyl disaster in 1986.

Radiological load of people who inhabit certain area, taking into account the size of the observed group, may be calculated at the level of an individual ("professional radiation"), of a group ("critical group"), or of the whole population, *i. e.*, population of a country, region, *etc*. From the medical-geographic aspect, investigations of natural radiological loads of the overall population of Serbia are important for spatial planning and protection, so the following text will contain the results of the investigations conducted so far in this area.

However, it has to be emphasized that according to the recommendations made by the International Commission on radiological Protection (ICPR), there is no permitted dose of radiation for the whole population on a certain territory; consequently, there is no permitted dose for natural radiological load either.

According to Petrović and Mitrović [13], natural radiological load (NRL) of the population of Serbia, expressed as the annual equivalent dose, basically depends on the intensity of the exposure dose (X) in a REA, and it ranges between 20 and 200 mSv per year (tab. 3). Expressed percentally, REA IV covers the largest area (43.35%), with the value of the exposure dose intensity of 0.8 pC/kgs, while REA VII–XI, having the values of the exposure dose intensity of 1.3-2.0 pC/kgs, each cover less than 1% of the territory of Serbia (fig. 1).

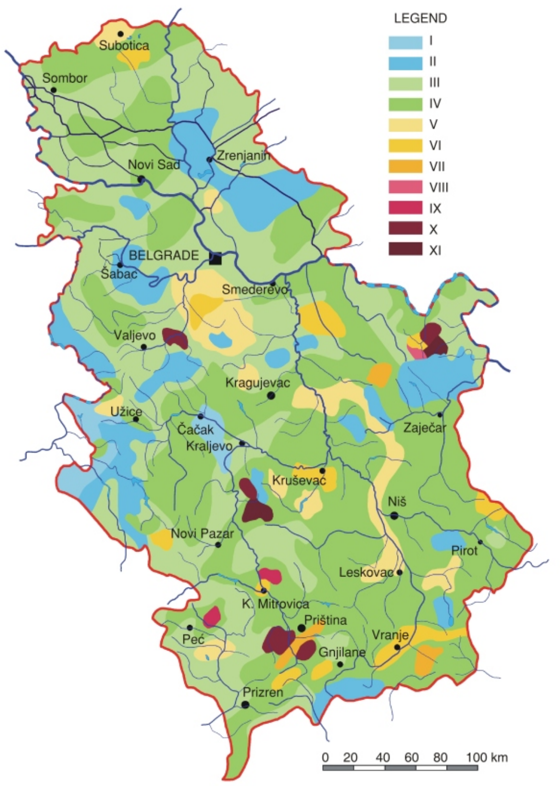

Figure 1. Geographic distribution of radio-ecological areals (REA) depending on the intensity of the exposure dose of gamma radiation (X) in Serbia
** Legend for the map is provided in tab. 3*
Source: Obradović [16] (adapted from Petrović and Mitrović [13]

(3) Petrović and Mitrović [13] provide the results of numerous radio-epidemiological studies which have shown significant correlation between the increased concentration of radon (^{222}Rn) in drinking water and higher rate of malignant diseases among autochthonic population (in the area of Devon in Great Britain, then in the states of Iowa and Illinois in the USA, *etc*.). Also, numerous researchers came to the results which show that the bones of those persons who had died of leukemia had as much as twice higher radioactivity in gamma emitters than the bones of those people who had died of traumatic fractures (different injuries) [14].

(4) Background radiation of the biosphere implies the *field of environmental gamma radiation.* It is expressed through the dosimetric value of *intensity of the exposure dose* (*X*), whereas the dosimetric SI unit for that dose is pC/kgs.

Table 3. Natural radiological load (NRL) of Serbian population

PEA	I	II	III	IV	V	VI	VII-VIII	IX-X	XI
X [$pCkg^{-1}s^{-1}$]	0.2	0.4	0.6	0.8	0.9	1.0	1.3-1.4	1.6-1.8	2.0
NRL [mSv per year]	20	40	60	80	90	100	130-140	160-180	200

Source: Petrović, Mitrović [13]

RADIOLOGICAL RISK ASSESSEMENT FOR POPULATION OF SERBIA

Based on the results of investigations conducted by Petrović and Mitrović [13], as well as on the basis of the risk coefficients provided for in the ICRP recommendations [15], a radiological risk assessment has been performed for the population of central Serbia for the census years of 1981, 1991, and 2002, assessing the risk of natural external radiation and the radiological risks occurring due to the introduction of natural radionuclides into the organism [16]. The results have been provided in tab. 4.

The radiological risk for the population of Serbia originating from external and internal ionizing radiation has been calculated using the following formulae [13]:

External radiation of the population
$N_{ks} = N\ f\ S_{RO}$
Internal radiation of the population
$N_{ku} = N\ f\,U_{RO}$, and
Total natural radiation
$N_{ki} = N f I_{RO}$
where N_k is the expected number of malignant tumors at the annual exposure (N_{ks} – due to external radiation, N_{ku} – due to internal radiation, N_{ki} – due to integrated, total radiation), N – the number of inhabitants of Serbia without provinces for the given census year (1981 – 5 694 464, 1991 – 5 808 906, 2002 – 5 466 009), f – the mean coefficient of risk for the population of Serbia, $f = 1.1 \cdot 10^{-2}$ per Sv, $S_{RO} = 9.15\ 10^{-4}$ Sv per year – external radioactive radiation, $U_{RO} = 4.5\ 10^{-4}$ Sv per year – internal radioactive radiation, $I_{RO} = 1.35\ 10^{-3}$ Sv per year – integrated radioactive radiation.

Table 4. Total expected number of malignant tumors in Serbia without provinces, according to the census years, occurring due to natural external and internal radiation

Natural radiation	Number of malignant tumors according to census years		
	1981	1991	2002
Natural gamma background radiation (external radiological radiatiion) (N_{ks})	57	58	55
Natural radionuclides (internal radiological radiation) (N_{ku})	28	29	27
Total natural radiological load (N_{ki})	85	86	81

Source: Obradović [16]

As provided in tab. 4, changes expected in the overall number of malignant tumors originating from natural radiation are primarily related to changes in number of the inhabitants of Serbia.

The exposure of the population to ionizing radiation may lead to the occurrence of acute radiological illness, chronic radiological illness, tumors, as well as of genetic defects to progeny (damages to chromosomes occurring due to ionizing radiation effects on reproduction organs/cells) [17].

On the basis of the research in central Serbia (project A/3, 1983) for the period between 1945 and 1983, it may be concluded that the radiological risk from the environment in central Serbia related to malignant diseases amounts to approximately 1.17% of the total number of malignant diseases [13].

In the long run, irradiation of the population originating from natural radionuclides in the environment is constant and chronicle. To this end, we may speak about a relatively unchanged incidence of genetic damages, whereat it is taken that there are 300 ill people in a population of one million inhabitants irradiated by 0.01 Sv per year. Bearing in mind that the equivalent dose (H) for radiation originating from natural radionuclides in Serbia amounts to 1.3 mSv per year, this means that the genetic risk assessment for the population of 5 million people amounts to 195 cases annually, or 213 cases in the population of central Serbia (according to census held in 2002)(5).

THE EFFECTS OF HIGH AND LOW DOSES

It is obvious that all the people are exposed to external and internal ionizing radiation, both from natural and artificial sources of ionizing radiation. Harmful effect of high and low doses on human body was discovered long time ago, whereas harmful effect linearly depends on the dose – the higher the dose of radiation, the higher the harmful effects on human health.

However, scientists have argued for a long time about the effects of lower doses to human health, *i. e.*, doses that do not cause clinical symptoms, as is the case with high and medium doses. There were several opposite opinions; on one hand, not only was the harmful effect non-existent, but there was a sort of a positive effect present [18], and on the other hand, it was claimed that effects of low doses were also harmful, but were difficult to establish since most commonly in such cases there were the so called "hidden changes". This second group

(5) $N_g = 5\ 10^6\ \ 1.3\ 10^{-3}\ \ 3\ 10^4\ \ 10^{-6} = 195$, where N_g – estimated number of cases with genetic damages, $5\ 10^6$ – five-million population, $1.3\ 10^{-3}$ – equivalent dose (H) for radiation coming from natural radionuclides in Serbia, $3\ 10^4\ 10^{-6}$ – 300 cases in one million inhabitants.

of opinions had a mismatch of standpoints related to whether such a harmful effect grew according to the linear or non-linear correlation. Investigations conducted by two organizations – UNSCEAR and BEIR – between 1980 and 1984 led to the conclusion that low doses of ionizing radiation also had considerable bio-negative effect which was expressed according to a linear dependence without a threshold. This also confirmed the notion of the American genetic scientist W. Morgan, who stated, that "there are no such low doses of ionizing radiation that do not cause changes to genetic material of living organisms" [13].

CONCLUSIONS

Based on the investigations performed so far, the following two conclusions could be made:
– there is no radiation threshold below which there are no health risks, and
– the risk increase is in a direct proportion with the dose received.

According to the Bylaw on limits of exposure to ionizing radiation [19], the recommended limit is 1 mSv per year, and it pertains to the sum of certain doses of the external exposure and the expected effective dose of the internal exposure to an artificial radiation source in a year time. However, there are no limit values for natural ionizing radiation, taking into account the results of the previously mentioned studies on small radiation doses (harmful effects were established for higher doses long time ago). Therefore, from the genetic aspect, the consequences of small doses effects may be expressed in the second generation, or even several generations later.

Knowing background radiation of the biosphere, *i. e.*, the size of the radiological field of gamma radiation in the environment could have significant impacts on spatial and urban development planning. This is particularly important when the location is to be determined for new settlements or new industrial facilities, especially when locating facilities for the production of food of plant and animal origins.

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ПРИРОДНО ЈОНИЗУЈУЋЕ ЗРАЧЕЊЕ И ЗДРАВЉЕ СТАНОВНИШТВА СРБИЈЕ

У раду су приказани потенцијални ефекти природног јонизујућег зрачења на здравље становништва. Посебан акценат стављен је на природне радионуклиде, као и на здравствене ефекте великих и малих доза. У раду су издвојени радиоеколошки ареали, и извршена процена радијационог ризика за становништво Србије према пописним годинама.

Кључне речи: природно јонизујуће зрачење, здравље, Србија