CORRELATION ANALYSIS OF GAMMA DOSE RATE FROM NATURAL RADIATION IN THE TEST FIELD

by

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This paper deals with correlation analysis of gamma dose rate measured in the test field with the five distinctive soil samples from a few minefields in Federation of Bosnia and Herzegovina. The measurements of ambient dose equivalent rate, due to radionuclides present in each of the soil samples, were performed by the RADIAGEM™ 2000 portable survey meter, placed on the ground and 1 m above the ground. The gamma spectrometric analysis of the same soil samples was carried out by GAMMA-RAD5 spectrometer. This study showed that there is a high correlation between the absorbed dose rate evaluated from soil radioactivity and the corresponding results obtained by the survey meter placed on the ground. Correlation analysis indicated that the survey meter, due to its narrow energy range, is not suitable for the examination of cosmic radiation contribution.

Key words: gamma dose rate, natural radiation, survey meter, gamma spectrometer, test field, correlation

INTRODUCTION

A few countries of Europe, especially Bosnia and Herzegovina are still contaminated with buried landmines [1]. However, the present landmine detection technologies are very dangerous, expensive, time consuming, and not effective enough. Thus, the development of more efficient, fast and robust, detection technology is of high priority. One of the promising alternative methods for detection of buried landmines is based on a combination of advanced nuclear techniques for humanitarian demining [2] with other methods like ground penetrating radar, or infrared imaging [3]. Improvement of combined detection systems can be achieved taking into account the local soil properties, such as soil composition and moisture distribution, as well as terrestrial radiation contribution. In order to investigate the critical parameters for application of the integrated landmine detection methods, the test field with the five distinctive types of soils, from the different locations in Federation of Bosnia and Herzegovina (B&H), close to the buried landmines, was formed in the north-eastern part of B&H [4, 5].

The natural radioactivity is manly consisted of terrestrial and extra-terrestrial components. The extra-terrestrial radiation stems largely from cosmogenic radionuclides produced by the interaction of cosmic-ray particles in the atmosphere of Earth while terrestrial radiation is due to radionuclides with half-lives comparable to the age of the Earth such as ^{40}K, and the radionuclides from the ^{238}U and ^{232}Th series. Terrestrial gamma radiation depends significantly on the soil composition and geographical conditions. Cosmic radiation increases with the altitude but it is less variable than the terrestrial component of natural radiation at different geographical latitudes [6].

Investigation of natural radiation in the test field was performed by the RADIAGEM™ 2000 portable survey meter [7] and the GAMMA-RAD5 spectrometer [8].

The main objective of this study was to investigate the terrestrial and cosmic radiation components of natural radiation in the test field, in order to get additional data on gamma dose rate that could be useful for application of the integrated landmine detection systems. Such detection systems are of great interest for workers active in demining of the minefields and for other people who spend more time outdoors in the examined area. Establishing of a reference data set on natural gamma radiation is essential to monitor the changes of radioactivity in the environment due to human activities, since the detection of radioactive contamination significantly depends on the background level. The gamma dose rate variability in the test field, as well as

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the estimation of cosmic dose rate component on the basis of the experimental data and correlation plot, are also presented and discussed in this paper.

MATERIALS AND METHODS

Characteristics of the test field

The test field (GPS coordinates N44°24'47.3", E18°25'08.0") was located in Banovici, village Pribitkovici, at 490 m above sea level, in the Tuzla Canton, in the north-eastern part of Bosnia and Herzegovina. The test field was formed by the five distinctive soil samples, collected in the vicinity of the minefields in Mostar (N43.34, E17.81), Sarajevo (43.85, E18.36), Travnik (N44.23, E17.67), Brcko (N44.87, E18.81), and Banovici (location of the test field). The collected samples were previously cleared from plant debris, small stones and other impurities. All soil samples had a cylindrical form with diameter of 60 cm and depth of 70 cm, which is more than 6 mean free paths of the most energetic natural gamma photons and therefore, sufficient to achieve the saturation of the dose rate [9]. Each soil sample was separated from the others in the test field by impermeable folia. Components of the soil samples, as well as their bulk densities are given in reference [10].

Soil radioactivity measurements by the GAMMA-RAD5 spectrometer

A few soil samples in the test field, collected from around the minefields in the Federation of Bosnia and Herzegovina, were investigated by the GAMMA-RAD5 integrated gamma-ray spectrometer. The soil sampling method was applied following the standard procedure recommended by the International Atomic Energy Agency [11]. The soil sampling for gamma spectrum measurements was performed from the surface of different soil samples up to 10 cm in depth, so that four samples were taken from the corners of the square inscribed in each circle with radius of 60 cm and one sample from the intersection of the diagonals. The small soil samples were then taken to the laboratory, where they were subsequently dried at a temperature of 100 °C, powdered and then packed in air-tight cylindrical plastic containers of 300 ml capacity. The packed samples were stored for 30 days in order to attain secular equilibrium between ^{238}U and its daughter products.

Gamma-spectrometric measurements of the soil samples were carried out using the GAMMA-RAD 5 spectrometer, which includes a NaI(Tl) scintillation detector, of standard size 76 mm   76 mm (3"   3") and other standard modules, necessary for measurement and analysis of gamma spectrum. The dynamic range of the detector is was from 10 to 3000 keV, while resolution was less than 7 % at 662 keV and 5 % at 1332.5 keV. The calibration of the detector was carried out using standard gamma source ^{60}Co (peaks at 1173.2 keV, 1332.5 keV and a coincidence line at 2505 keV) and ^{137}Cs (peak at 662 keV), which covered the energy range up to 2.5 MeV. The detector was placed in the center of a shield consisting of plastic layers with thickness of 20 mm and lead plates with thickness of 10 mm, in order to reduce the background counting rate. The experimental configuration remained the same for all the soil samples investigated during this study. The detector was connected to a multichannel analyzer (MCA) which was interfaced with a computer. Measurement of each gamma spectrum was carried out long enough to reduce the statistical errors. The SODIGAM software was used for analysis of the spectral data.

The specific activity of ^{40}K radionuclide was evaluated from one gamma photopeak with energy of 1460.8 keV. The specific activity of the ^{232}Th radionuclide was derived from the average value of photopeaks of its products ^{228}Ac (911.2 keV and 969 keV), and ^{212}Pb (238.6 keV). The specific activity of ^{226}Ra, assumed to be in radioactive equilibrium, was evaluated from the averaging gamma photopeaks for ^{214}Pb (351.9 keV) and ^{214}Bi (609.3 keV).

Measurements of ambient dose equivalent rate by the RADIAGEM^{TM} 2000 portable survey meter

The measurements of ambient dose equivalent rate in the test field were performed by the RADIAGEM^{TM} 2000 portable survey meter. Such a type of survey meter is suitable for the field measurements due to its fast response and the capability to locate the hot spots. The RADIAGEM^{TM} 2000 survey meter is an energy-compensated Geiger-Muller counter, in the gamma energy range from 40 keV to 1.5 MeV, with   15 % accuracy. It is used for measurement of ambient dose equivalent rate in the range from 0.01 Sv/h to 100 mSv/h. However, when compared to the instruments with an ion chamber or with a proportional counter, the RADIAGEM^{TM} 2000 survey meter provides less accurate results.

The body related dose quantity, such as effective dose, cannot be directly measured, and hence it is not suitable for radiation protection monitoring. For this reason, alternate quantities *i. e.* the operational quantities are used for the assessment of the effective dose. The ambient dose represents an estimate of the effective dose received by a person located at the point of the monitoring instrument [12]. The RADIAGEM^{TM} 2000 is a survey meter calibrated in units of ambient dose equivalent $H^*(10)$. Since the RADIAGEM^{TM} 2000 is an automatic device, there is no possibility to perform modifications of the conversion factors from counts to ambient dose equivalent. In order to check whether the values provided by the automatic device, are enough reliable for dosimetry surveys, the portable survey meter was tested in the laboratory, with the use of point gamma sources of negligible size. It was demonstrated that the experimental results are in good agreement with the calculated values of gamma dose rate in air [10].

RESULTS AND DISCUSSIONS

Estimation of gamma absorbed dose rate from soil radioactivity measurements

The specific activity of ^{226}Ra, ^{232}Th, and ^{40}K in the soil samples, located in the test field (given in tab. 2), varied in the range of 38-63 Bq /kg, 28-62 Bq/ kg, and 378-521 Bq /kg, respectively, with the corresponding mean values of 47 Bq/kg, 41 Bq/kg and 451 Bq/kg. The specific activities of ^{226}Ra, ^{232}Th, and ^{40}K, observed in the test field, were compared to the worldwide average values and it was found that the overall mean values of specific activities do not deviate significantly from the worldwide average values of 32, 45, and 412 Bq/kg, respectively [6]. The results of this study revealed that there was no significant variation of specific activities of these radionuclides in the soil samples which was expected, since the composition of the soil samples was not highly different. It can be noticed that the Sarajevo soil samples without gravel has the lowest specific activity while the Travnik soil sample with high concentration of gravel has the largest value of specific activity.

The absorbed dose rates (expressed in nGy/h), were estimated from the values of specific activity of ^{226}Ra, ^{232}Th, and ^{40}K in soil, by using the dose coefficients given in reference [6]

$$\dot{D} \quad 0.462 C_{\mathrm{U}} \quad 0.604 C_{\mathrm{Th}} \quad 0.0417 C_{\mathrm{K}} \tag{1}$$

where, C_{U}, C_{Th}, and C_{K} are the specific activities of ^{238}U, ^{232}Th, and ^{40}K in soil, expressed in Bq/kg.

The radionuclide specific activities, estimated absorbed dose rate and annual effective dose without the cosmic ray component, are given in tab. 1. The absorbed dose rate due to ^{226}Ra, ^{232}Th, and ^{40}K, natural radionuclides, varied from 49.9 nGy/h to 86.0 nGy/h with the mean value of 65.0 nGy/h for all the soil samples, which is higher when compared to the worldwide average value of 54 nGy/h due to terrestrial radiation [6]. It was noticed that the gamma dose rates, estimated from soil radionuclide activities, does not vary significantly in the test field. The mean value of outdoor annual effective dose due to the terrestrial sources (^{226}Ra, ^{232}Th, and ^{40}K), for the five soil samples, was in the range of 0.07- 0.12 mSv, with the overall mean value of 0.08 mSv, which is close to the worldwide average value of 0.07 mSv [6].

In addition to natural radiation measurements, we also measured ^{137}Cs specific activity, in the same soil samples in the test field, in order to assess the possible risks for the population in the tested area. The presence of ^{137}Cs, with a half-life of about 30.17 years, could result from radionuclides fallout of previous worldwide nuclear weapons testing, past nuclear power plant accidents, as well as nuclear waste disposal. Since most of the fallout radiation accumulates in the soil, it was of interest to investigate the specific activity of ^{137}Cs in the soil samples. The results obtained are given in tab. 2. The specific activity of ^{137}Cs was evaluated from the gamma peak of 661.6 keV and it was found to be between 15 and 49 Bq/kg, with the mean value of 30.6 Bq/kg. The mean value of estimated external gamma dose rate, from all the soil samples, is 0.92 nGy/h and the mean value of annual outdoors effective dose is $1.1 \cdot 10^{-3}$ mSv, which is below the recommended value of 0.07 mSv from the outdoors external terrestrial radiation [6]. The results of this study indicate that the presence of ^{137}Cs radionuclide in the soil samples does not represent a hazard for the population in the examined area.

Table 1. Specific activities, estimated absorbed dose rate and annual effective dose, due to soil radionuclide activities, for the soil samples Brcko (B), Travnik (T), Mostar (M), Sarajevo (S), test field (TF)

Radionuclide specific activity [Bqkg^{-1}]	B	T	M	S	TF	Mean value	Median
^{226}Ra	51	63	44	38	40	47.2	44
^{232}Th	45	62	36	28	34	41.0	36
^{40}K	452	475	429	378	521	451	452
Estimated absorbed dose rate [nGyh^{-1}]	69.3	86	59.7	49.9	60.3	65.0	60.3
Annual effective dose [mSv^{-1}]	0.09	0.11	0.07	0.06	0.07	0.08	0.07

Table 2. Specific activities, estimated absorbed dose rate and annual effective dose due to ^{137}Cs radionuclide, for the soil samples in the test field

	B	T	M	S	TF	Mean value	Median
Specific activity [Bqkg^{-1}]	15	49	42	23	24	30.6	24
Estimated external dose rate [nGyh^{-1}]	0.45	1.47	1.26	0.69	0.72	0.92	0.72
Annual outdoors effective dose [mSv]$\cdot 10^{-4}$	6	18	15	8	9	11.3	8.8

Measurements of ambient dose equivalent rate by the survey meter

The first set of measurements in the test field was performed with the RADIAGEM^{TM} 2000 at 1 m from the soil surface. We performed 90 measurements of ambient dose equivalent rates, for each soil sample, in the test field. Every measurement was carried out for one minute and then the highest value during that time interval was taken. In order to perform a comparison between the survey meter results with the results obtained from radionuclide activities, we converted the survey meter results to absorbed dose rate in air. It was done by using the relationship $H^*(10) = 1.21\,K_a + 1.26$ between air kerma rates K_a in nGy/h and ambient dose equivalent rates $H^*(10)$ in nSv/h [13]. The air kerma is about equal to the absorbed dose in air under conditions that secondary charged particle equilibrium is attained [12].

The basic statistical parameters of the results, obtained after conversion of ambient dose equivalent rate measurements to absorbed dose rate for the set of measurements with the hand-held survey meter at 1 m distance from the ground in the test field, are given in tab. 3. The mean value of absorbed dose rate in air for all the samples in the test field is 41.7 2.8 nGy/h, in the range 7.2-164.2 nGy/h.

The histogram of 90 experimental results of dose rate and fitted log-normal function for the Sarajevo soil sample, when the survey meter was placed on the ground and at 1 m above the ground, are presented in fig. 1(a) and (b), respectively. Similar asymmetric histograms have been obtained for the rest of the soil samples in the test field. Parameters of the experimental data distribution and fitted log-normal distribution are given in tab. 4. It can be noticed that there is a good agreement between the parameters of the experimental data distribution and log-normal distribution.

One-way ANOVA test was applied to the experimental data, obtained by the survey meter at 1 m distance from the soil surface. P-value of 0.0231, as the result of a one-way ANOVA test, indicates that differences between the mean values of absorbed dose rates from the soil samples are not significant at a significance level of 0.05.

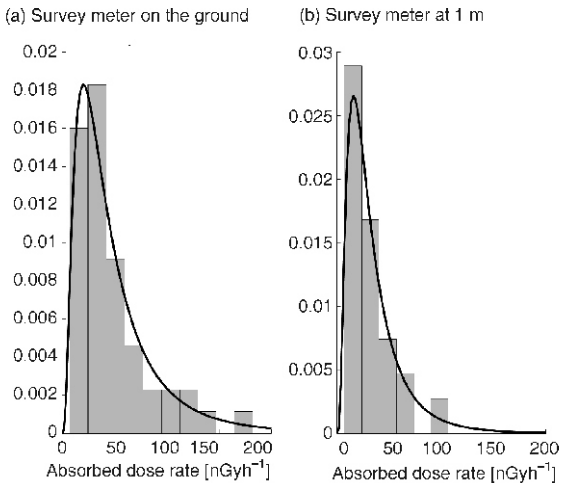

Figure 1. The histogram and fitted log-normal distribution for the Sarajevo soil sample when (a) the survey meter was placed on the ground and (b) the survey meter at 1 m height

The second set of measurements was performed with the survey meter placed on the soil surfaces in the test field. We carried out 50 measurements for each soil sample in the test field. Every measurement by the RADIAGEM^{TM} 2000 lasted for one minute, as in the previous set of measurements and then the highest value during that time was taken. The results of basic statistical analysis of absorbed dose rates obtained for the soil samples, using the survey meter on the ground, are given in tab. 5. The mean value of ambient dose equivalent rate for all samples is 64.9 6.5 nGy/h, in the range from 7.2 to 298.9 nGy/h. It can be noticed that the mean value of absorbed dose rate for all the samples, when the survey meter is on the ground, is higher than in the previous series of measurements, when the instrument was at 1 m distance from the ground.

It was performed a one-way ANOVA test of experimental data obtained by the survey meter on the

Table 3. The basic statistical parameters for gamma dose rate in air measured with the hand-held survey meter at 1 m distance from the ground in the test field

Descriptive statistics parameters	Sample Brcko	Sample Travnik	Sample Mostar	Sample Sarajevo	Sample test field
Median [nGyh^{-1}]	32.0	48.5	40.3	32.0	40.3
Mean [nGyh^{-1}]	40.0	46.3	43.9	34.1	44.2
Standard deviations (SD) [nGyh^{-1}]	31.2	25.3	26.7	22.9	27.9
SD of the mean	3.3	2.7	2.8	2.4	2.9

Table 4. Parameters (GM-geometric mean and GSD-geometric standard deviation) of the experimental data distribution and fitted log-normal distribution for both sets of measurements by the survey meter

Distribution	The survey meter at 1 m distance		The survey meter on the ground	
	GM [nGyh^{-1}]	GSD [nGyh^{-1}]	GM [nGyh^{-1}]	GSD [nGyh^{-1}]
Experimental data	27.1	2.04	37.8	2.2
Log-normal distribution	26.8	2.04	37.4	2.2

Table 5. Basic parameters of descriptive statistics for gamma dose rate in air, measured with the survey meter on the ground, in the test field

Descriptive statistics	Sample Brcko	Sample Travnik	Sample Mostar	Sample Sarajevo	Sample test field
Mean [$nGyh^{-1}$]	67.7	89.8	58.3	49.3	59.6
Median [$nGyh^{-1}$]	56.8	82.3	40.6	40.6	56.8
SD[$nGyh^{-1}$]	40.7	61.3	52.2	35.9	37.8
SD of the mean [$nGyh^{-1}$]	5.7	8.7	7.4	5.1	5.3
Range [$nGyh^{-1}$]	7.2-189.0	7.2-249.0	7.2-298.9	7.2-182.3	7.2-147.7

ground. P-value of 0.0004 is close to zero suggesting that at least one sample mean, of absorbed dose rate, is significantly different from means of the other samples, at a significance level of 0.05. Hence, the ground measurements by the survey meter provide the significant differences between absorbed dose rates from the soil samples in the test field.

Correlation between measured and estimated gamma absorbed dose rates

We performed the correlation analysis between gamma dose rates, measured by the RADIAGEM^{TM} 2000 survey meter and gamma dose rates, estimated from soil radioactivity. It was found that there is a significant positive correlation with a high value of correlation coefficient of 0.9968, between the outdoors gamma dose rate, measured with the RADIAGEM^{TM} 2000 survey meter on the ground, in the test field and gamma dose rates estimated from soil radioactivity. It was observed somewhat lower value of correlation coefficient of 0.6853 when the RADIAGEM^{TM} 2000 survey meter was placed 1 m above the ground. The weaker correlation in that case is due to a contribution of much larger soil volume, of different composition, with more soil homogeneity, when compared to small soil volume, taken for spectrometric analysis. The correlation plot between dose rate estimated from soil radioactivity and outdoors dose rate measured directly using the survey meter, for the series of measurements performed on the ground and at 1 m height, is given in fig. 2(a) and (b), respectively. It should be pointed out that the dose rate given on X-axis is estimated from soil radioactivity without taking into account the cosmic ray component. The values obtained on the soil surface are related mostly to the soil radionuclide concentrations, while the measurements performed at 1 m above the ground are affected by the surrounding soil of different composition. Correlation analysis showed that the values obtained by the survey meter on the ground represent the soil radioactivity and gamma dose rate more reliably than the values obtained at 1 m height.

The cosmic component of natural radiation should be estimated at the same place (the same longitude, latitude and altitude) where the terrestrial gamma radiation measurement was performed. Taking into account that the direct measurement of local cosmic

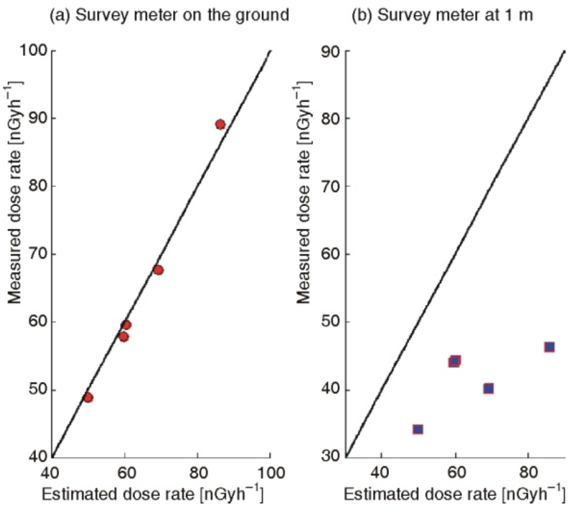

Figure 2. The correlation plot between gamma dose rate estimated from soil radioactivity and dose rate measured by the survey meter (a) on the ground and (b) at 1 m height

ray contribution at location of the test field was not possible [14] and that all the samples in the test field were exposed to the same secondary cosmic radiation, we tried to assess a contribution of the cosmic dose rate component by using the experimental data and the correlation plot [15].

Since the measured gamma dose rate on Y-axis includes terrestrial and cosmic ray components and the estimated dose rate on X-axis includes only terrestrial sources, the intercept in the correlation plot between the estimated and measured dose rate is related to the cosmic ray component. For the dose rates measured in situ 1 m above the soil surface in the test field the intercept in the correlation plot by using the least square method is 26.0 nGy/h (fig. 3).

The cosmic ray dose rate above sea level depends on the altitude according to [6]

$$E_1(z) \quad E_1(0)[0.21\mathrm{e}^{\;1.649z} \quad 0.79\mathrm{e}^{0.4528z}] \tag{2}$$

where $E_1(0)$ is the dose rate at sea level and z is the altitude expressed in km.

Taking into account that the test field is at an altitude of 490 m above sea level, the estimated value of the cosmic ray dose rate by using eq. (2) is 42.2 nGy/h. Since the average cosmic ray dose rate at sea level is 31 nGy/h it is obvious that the intercept of 26.0 nGy/h,

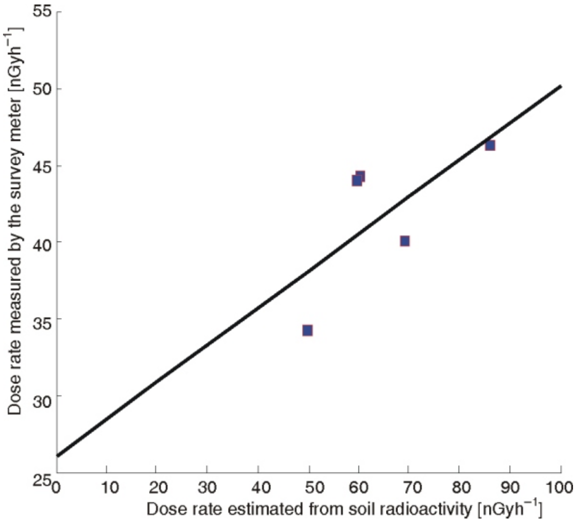

Figure 3. The correlation plot for estimation of the cosmic dose rate component

obtained from the experimental data, cannot be acceptable as an assessment of cosmic ray dose rate. Correlation analysis indicated that the contribution of cosmic radiation component cannot be detected by the RADIAGEM^{TM} 2000 survey meter, in the gamma energy range from 40 keV to 1.5 MeV. Due to the lack of a survey meter in a wider energy range, we could not conduct the further investigation on this subject.

In order to reveal more correlated signatures, we analyzed the joint probability density functions (JPDF) of various parameters. The JPDF of estimated dose rate-sand content (%) in the soil samples and estimated dose rate-gravel content (%) in the soil samples distributions, are shown in fig. 4(a) and (b), respectively. It can be seen in fig. 4 (a), that there is a negative moderate correlation between sand content in the soil samples and dose rate measured by the survey meter, while the JPDF given in fig. 4(b) shows that there is a positive moderate correlation in the case of gravel content and dose rate distribution.

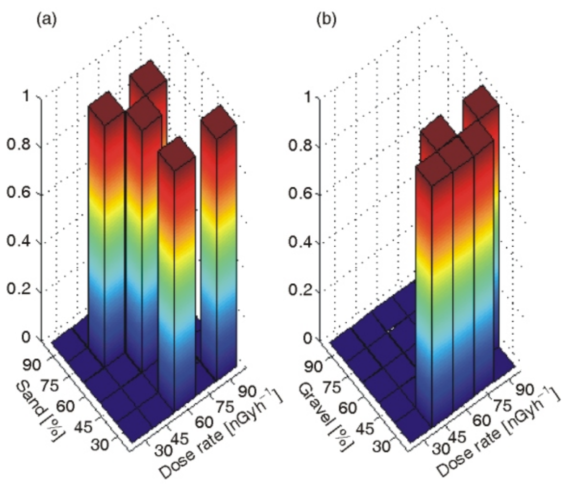

Figure 4. The JPDF of estimated dose rate-sand content [%] distribution (a) and estimated dose rate-gravel content [%] distribution (b) in the soil samples

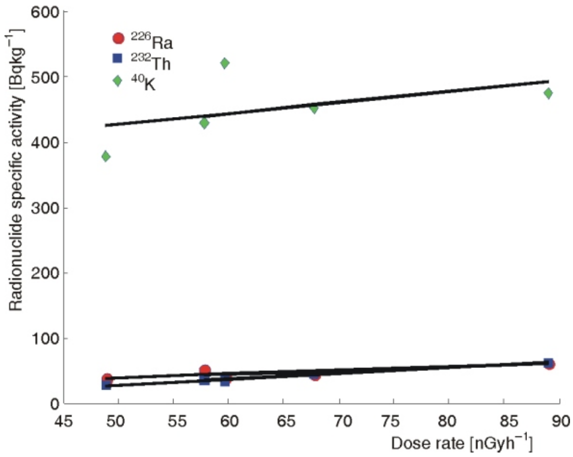

Figure 5. The correlation between the dose rate measured by the survey meter on the ground and specific activities of radionuclides from the soil samples

The correlation plot between the dose rate measured by using the portable survey meter on the ground and the corresponding specific activities of ^{40}K, ^{226}Ra, and ^{232}Th radionuclides in the soil samples, in the test field, are given in fig. 5. It can be noticed that the correlation between dose rates and specific activities of ^{226}Ra and ^{232}Th is higher when compared to that obtained between dose rate and specific activity of ^{40}K.

CONCLUSIONS

The integrated systems for landmine detection, such as the systems based on a combination of the nuclear methods, with other methods like ground penetrating radar, or infrared imaging, are significantly affected by soil type and moisture. Incorporation of experimental data on soil properties, as well as the levels of natural radiation, into the sensor fusion process, has the potential to improve the performance of multisensor landmine detection systems.

We formed the test field in the north-eastern part of Bosnia and Herzegovina, with the five soil samples from different parts of B&H, to investigate terrestrial gamma radiation, as well as cosmic ray component of natural radiation, at the same altitude and under the same cosmic radiation and weather conditions. The radiological study in the test field was performed by the RADIAGEM^{TM} 2000 portable survey meter and the integrated GAMMA-RAD5 spectrometer. The mean value dose rate, observed for the test field, does not deviate significantly when compared to the worldwide mean value. The correlation analysis showed that there is a high correlation between the estimated absorbed dose rate from soil radioactivity and the results obtained when the survey meter was placed on the ground. The ground results, in contrast to the measurement results at 1 m height, showed that the differences between the mean values of gamma dose rates, from the different soil samples in the test field, are at statistically significant level.

There was a possibility to assess a contribution of cosmic ray dose rate from the experimental data and a correlation plot with a higher accuracy, taking into account that all samples in the test field were exposed to the same cosmic radiation and were under the same weather conditions. The correlation analysis indicated that the survey meter, due to a narrow energy range, cannot detect the cosmic radiation contribution. Since there is no survey meter available for us in a wider energy range, we could not continue the investigation of cosmic radiation component from the experimental data.

The results of this study are of public interest in the examined area, especially for workers active in demining of minefields and other people who spend more time outdoors. Since contamination of the area by the man made radionuclides strongly depends on the background level, which mainly stems from terrestrial gamma radiation, the experimental results of this radiological study could be useful for assessing the level of potential radioactive contamination in the tested area.

In the next phase of our research activity we have planned to apply the combined method for uncertainty evaluation in radiation measurements, in order to expand analysis of the measurement results and improve quantitative statements about accuracy of experimental data, obtained in the field measurements of gamma radiation [16, 17].

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AUTHORS' CONTRIBUTIONS

B. Pehlivanovic and M. Music performed the experimental investigations while S. Avdic and A. Osmanovic dealt with processing of experimental data. All the authors participated in analysis and discussion of the results presented, and in preparation of figures, tables and text of the manuscript.

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КОРЕЛАЦИОНА АНАЛИЗА ЈАЧИНЕ ГАМА ДОЗЕ КОЈА ПОТИЧЕ ОД ПРИРОДНОГ ЗРАЧЕЊА У ТЕСТ ПОЉУ

Овај рад бави се корелационом анализом јачине гама доза, мерених у тест пољу које је формирано са пет различитих узорака тла, у близини минских поља, у Федерацији Босне и Херцеговине. Мерење јачине амбијенталног дозног еквивалента услед радионуклида у узорцима тла извршено је помоћу RADIAGEM^{TM} 2000 портабл мерача доза гама зрачења, на површини тла и на висини од 1 m изнад тла. Гама спектроскопска анализа истих узорака тла урађена је применом GAMMA-RAD5 спектрометра. Ова студија показала је да постоји висока корелација између јачине апсорбоване дозе, евалуиране на основу радиоактивности узорака тла и одговарајућих резултата мерених помоћу портабл дозиметра, постављеног на површину узорака тла. Корелациона анализа указује да портабл дозиметар, услед уског енергетског опсега, није погодан за испитивања доприноса компоненте космичког зрачења.

Кључне речи: јачина гама дозе, природно зрачење, гама спектрометар, тест поље, корелација