ASSESSMENT OF A RELATIVE CONTRIBUTION OF TERRESTRIAL BACKGROUND RADIATION IN THE TEST FIELD BY USING RADIAGEM™ 2000 PORTABLE SURVEY METER

by

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This study is focused on the radiological investigation of terrestrial gamma radiation in the test field with soil samples from different minefields in the Federation of Bosnia and Herzegovina. Measurements of ambient dose equivalent rate, commonly referred to as "air dose rate", in the test field located in the Tuzla Canton, were performed by RADIAGEM™ 2000 portable survey meter, based on energy-compensated Geiger-Muller counter. Its performances were tested in the laboratory conditions with gamma point sources. Since all the samples in the test field were exposed to the same cosmic radiation, there was a possibility to assess a relative contribution of terrestrial gamma radiation due to soil samples of different composition. One set of measurements in the test field was performed with RADIAGEM™ 2000, at a height of about one meter above the ground and basic statistical parameters indicated that there was no significant difference of terrestrial gamma radiation from different soil samples. The other set of measurements was carried out with the same device placed on the ground in the test field. Processing of experimental data on terrestrial gamma radiation has shown that it was possible to make a difference between relative contributions of terrestrial gamma radiation from individual soil samples. The results of investigation could be useful for multiple purposes of public interest.

Key words: RADIAGEM™ 2000, survey meter, terrestrial gamma radiation, soil sample, minefield

INTRODUCTION

A few countries of the world are still facing the problem of heavy mine contamination, among them Bosnia and Herzegovina. So far only the conventional methods for demining have been applied in the minefields located [1-3]. However, such methods are extremely dangerous, time consuming and expensive. Improvement of the efficiency of landmine detection systems and development of alternatives methods to the conventional ones are of high interest. Nuclear method based on neutron and/or gamma-rays detection is one of the most promising methods for landmine detection, which strongly depends on soil composition [4]. Since characteristics of a few individual landmine sensors depend on soil properties, incorporation of information about the local soil environment, including the terrestrial background radiation into the integrated sensor system, could improve the performance of multi-sensor landmine detection systems [5].

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A radiological study of the limited scope was carried out in the test field at 490 m above sea level in the Tuzla Canton, the north-eastern part of Bosnia and Herzegovina [6]. The test field was formed by five distinctive soil types sampled close to the minefields in Mostar, Sarajevo, Travnik, Brcko and Banovici (location of the test field). Investigation of natural radiation in the test field was performed by RADIAGEM™ 2000 portable survey meter [7].

Natural radioactivity manly originates from the cosmogenic radionuclides produced by the interaction of cosmic-ray particles in the atmosphere of the Earth and terrestrial 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. The three naturally occurring terrestrial radioisotopes ^{238}U, ^{235}U, and ^{232}Th emit neutrons through the spontaneous fission process and contribute to neutron backgrounds, as well as neutrons produced from (α, n) reactions, although their contribution is almost negligible [8]. However, neutrons cannot be monitored by the available RADIAGEM™ 2000 survey meter and they are not of interest in this study. The largest contribu-

tion to external source of irradiation of the human body stems from gamma-emitting radioactive elements in the ground [9]. Terrestrial gamma radiation (TGR) mainly depends on geological and geographical conditions [10]. The composition of the ground significantly influences TGR at any given place.

The cosmic component of natural radiation should be estimated at the same place (the same longitude, latitude and altitude) where the experiment was organized. The secondary particles created by the primary cosmic radiation such as muons, photons, and neutrons have a strong penetrability through air and they can reach the sea level directly. Since the energy of cosmic gamma photons is larger than 1 MeV and RADIAGEM^{TM} 2000 is sensitive to gamma photons up to 1.5 MeV, there is a possibility to detect cosmic gamma photons by using this survey meter. It was not possible to measure the local cosmic ray contribution at the location of the test field [11]. However, taking into account that all samples in the test field were exposed to the same secondary cosmic radiation, we could assess the contribution of TGR above each soil sample in the test field relatively to the total dose rate, including the contribution of TGR and also the contribution of secondary cosmic radiation.

The main objective of this study was to investigate whether the RADIAGEM^{TM} 2000 device is sensitive enough to detect the terrestrial gamma radiation differences from five various soil types sampled in vicinity of a few minefields in the Federation of Bosnia and Herzegovina, as well as to consider possible applications of the results obtained for multiple purposes of public interest.

This paper is organized as follows: the next section presents examination of the RADIAGEM^{TM} 2000 survey meter performances; then follows analysis of the experimental results due to TGR obtained in the test field and in the final section conclusions are provided.

EXAMINATION OF THE RADIAGEM^{TM} 2000 SURVEY METER PERFORMANCES

For instant measurements of ambient dose equivalent rate we used RADIAGEM^{TM} 2000 portable survey meter. RADIAGEM^{TM} 2000 is an energy-compensated Geiger-Muller counter with 15 % accuracy in the gamma energy range from 40 keV to 1.5 MeV. It is designed for measurement of ambient dose equivalent rate in the range of 0.01 Sv/h to 100 mSv/h. One advantage of such kind of survey meter is that there is a possibility to get a fast response in the field measurements and locate hot spots or any spot where the radiation shielding is not appropriate. On the other hand, RADIAGEM^{TM} 2000 survey meter provides less accurate results of the dose rate measurements compared to the instruments with an ion chamber or with a proportional counter.

RADIAGEM^{TM} 2000 survey meter is routinely calibrated in units of ambient dose equivalent $H^*(10)$, since it is the operational quantity which is relevant for such surveys according to ICRP. The body related dose quantity, such as effective dose, cannot be directly measured, since it requires knowing the doses delivered to all the major organs in the body and is not directly suitable for radiation protection monitoring. Therefore, alternate quantities, *i. e*., the operational quantities are used for the assessment of effective dose or mean doses, in tissues or organs. The ambient dose represents an estimate of the effective dose received by a person, staying at the point of the monitoring instrument [12].

RADIAGEM^{TM} 2000 is an automatic survey meter and includes a factory calibration so, there is no possibility to perform modifications of the conversion factors from counts to ambient dose equivalent. Hence, there is the need to check whether the values provided by the automatic device are enough reliable for dosimetry surveys. The sensitivity of the portable survey meter was tested with the use of gamma point sources of negligible size and low activity such as ^{60}Co source with the activity of 0.14 μCi or 5.14 kBq and ^{137}Cs source with the activity of 3.54 μCi or 0.13 MBq. Measurements were performed in the laboratory conditions. Both sources were placed at the distance of 1 m from the survey meter and no significant increase above the background level was registered, taking into account the uncertainties of measurements. Just at distance of 0.25 m from the both sources, the survey meter response was significantly larger, compared to the background level. The values of ambient dose equivalent rate obtained by RADIAGEM^{TM} 2000, according to reference [13] represent the "air dose rate". The results of the one-way ANOVA test, given in fig. 1, confirmed our observation. Since p-value of $1.61 \cdot 10^{-11}$ is close to zero, it can be concluded that the mean value of ambient dose equivalent rate, at the distance of 0.25 m from both sources, is significantly different from the mean value of ambient dose equivalent rate of

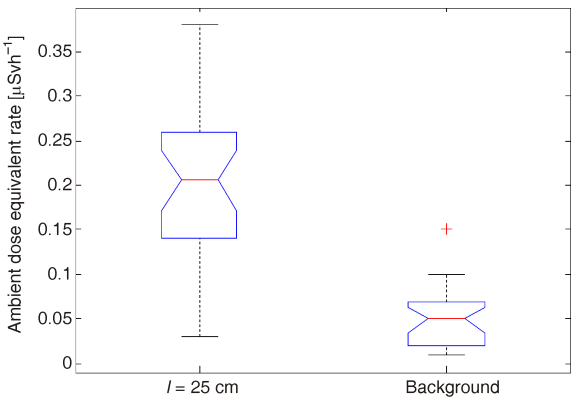

Figure 1. The results of the one-way ANOVA test of ambient dose equivalent rates in the laboratory

background radiation, at significance level of 0.05. We performed a simple Monte-Carlo simulation of the experiment by using the MCNPX transport code [14]. The survey meter was modelled as a cylinder with the height of 4 cm and radius of 0.6 cm, according to the manufacturer data. Contribution of both individual sources was simply summed. The calculated results of 0.1925 μSv/h, obtained at the distance of 0.25 m from the both sources, are in very good agreement with the mean experimental value of 0.1941 0.0098 μSv/h for ambient dose equivalent rate.

In addition, we compared the results of the MCNPX calculations of ambient dose equivalent rate at various distances from the ^{137}Cs source (3.57 μCi or 0.13 MBq, measurement was performed somewhat earlier than the previous one so that the activity of the same ^{137}Cs source was larger at the moment of measurements) with the experimental values obtained by using RADIAGEM^{TM} 2000 in the laboratory conditions. Since we do not have detailed information available about the device dimensions and composition, the simulation model was very simple, taking into account cylindrical geometry of the GM survey meter and point geometry of gamma source. The back-scattering contribution of the walls, floor and ceiling of the laboratory was not considered in the simulation. Taking into account that survey meter, based on GM detector, measures correctly only for the calibration conditions and that we used the simplified model in the calculations, the experimental and calculated values for air dose rate are in good agreement, except at distances less than 3 cm from the sources, with relative difference more than 35 %. The experimental values for ambient dose equivalent rate, commonly called as "air dose rate", including error bars and the results of our MCNPX calculation as a function of distance from the source, are given in fig. 2. The air dose rate is expressed in Sv/h in this paper according to the recent reference [13]. The results obtained indicate that the RADIAGEM^{TM} 2000 survey meter performs well in the presence of contaminated surfaces, even with radioactive materials of low activity.

In order to evaluate the fluctuations in the ambient dose equivalent rates and count rates, we carried out 60 measurements of radiation background in the laboratory conditions, with RADIAGEM^{TM} 2000 survey meter, at a fixed position [11]. Taking into account that sensitivity of this type of survey meter is about 3000 counts per μSv for one hour [7], the counts distribution was considered. The histogram of 60 experimental results, for indoor background radiation, taken over one minute each, is given in fig. 3. The solid curve represents the simulated Gauss distribution, while the histogram represents the occurrence frequency of the experimental data. The distribution was normalized for the observed mean value. It is well known that the Poisson distribution approaches the Gaussian distribution for a large mean value of count rate. It can be calculated that the standard deviation represents about 10 % of the mean value, which means that this value can be used as the minimum uncertainty of one measurement, due to the process of radiation emission and detection process itself.

ANALYSIS OF THE EXPERIMENTAL RESULTS OBTAINED IN THE TEST FIELD

Test field was situated at the location with GPS coordinates N 44°24' 47.3", E 18° 25' 08.0" (Banovici, village Pribitkovici), about 40 km away from Tuzla (fig. 4). The test field was composed of five distinctive soil types from locations close to the minefields in Mostar, Sarajevo, Travnik, Brcko and Banovici (location of the test field). All the samples had a cylindrical form, with diameter of about 60 cm and down to 70 cm in depth. Depth of each soil cylinder was greater than two or three photon mean free-path lengths in the soil

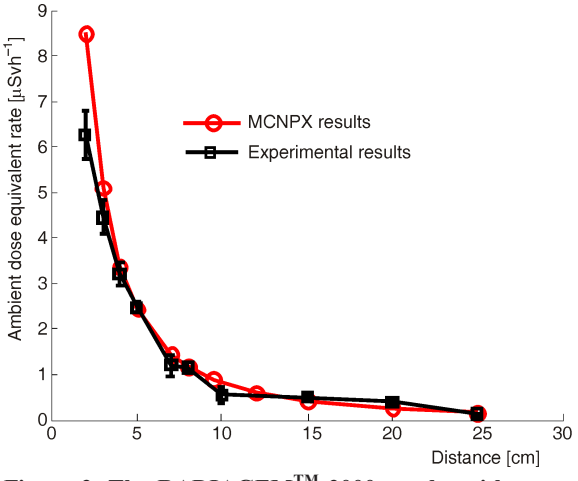

Figure 2. The RADIAGEM^{TM} 2000 results with error bars and the MCNPX calculation results of ambient dose equivalent rate (called "air absorbed dose") as a function of the distance from the ^{137}Cs source

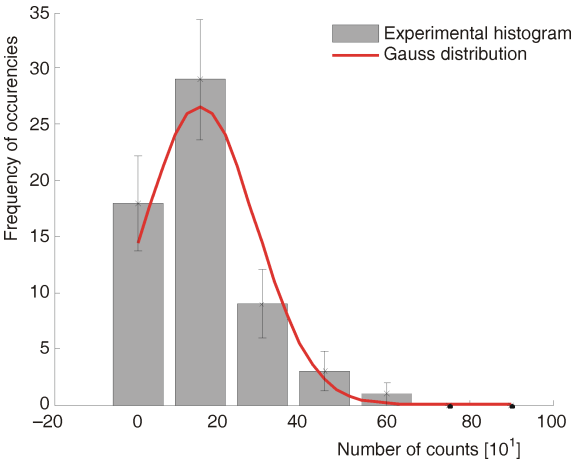

Figure 3. Histogram of experimental data and Gauss curve fitted to the data

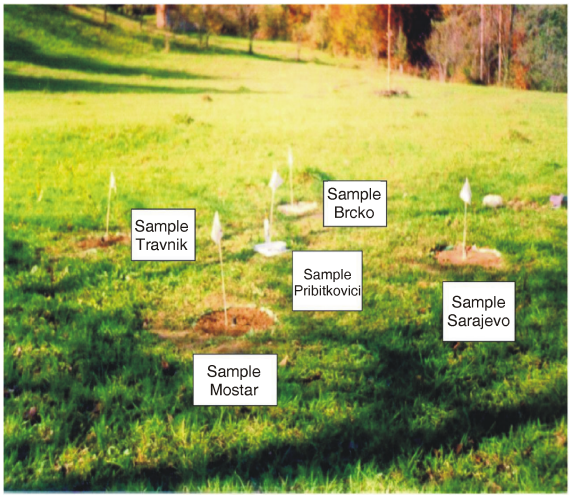

Figure 4. The test field with soil samples

[11]. The soil sample components, as well as their bulk densities, are given in tab. 1.

One set of measurements in the test field was performed with RADIAGEM^{TM} 2000 about one meter from the ground. We performed 90 measurements of ambient dose equivalent rates for each sample in the test field. The survey meter measured for one minute and then the highest value during that time interval was taken. The first series of measurements was carried out in November 2015.

Basic parameters of descriptive statistics of ambient dose rates, obtained for soil samples using hand-held survey meter at 1 m above the ground, are given in tab. 2. The mean value of ambient dose equivalent rate for all samples is 0.0517 0.0033 Sv/h, in the range from 0.01 to 0.20 Sv/h.

P-value of 0.0231, as the result of a one-way ANOVA test, is not very small and it indicates that differences between soil samples means are not significant (fig. 5). The null hypothesis that samples drawn from the same population cannot be rejected at significance level of 0.05. Hence, there are no significant differences between ambient dose equivalent rates from

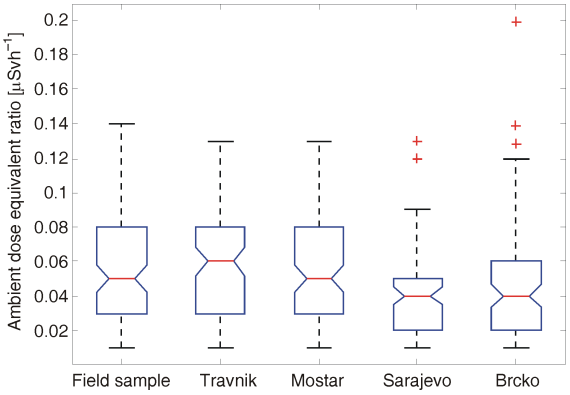

Figure 5. The results of a one-way ANOVA test of ambient dose equivalent rate for soil samples in the test field

soil samples, although some basic statistical parameters show that the relative contributions of TGR from the Sarajevo and Brcko samples are more similar than the other ones due to their similar soil composition, given in tab. 1.

Histograms of the experimental data with uncertainties obtained in the test field, are given in fig. 6. It can be observed that histograms for the Sarajevo and

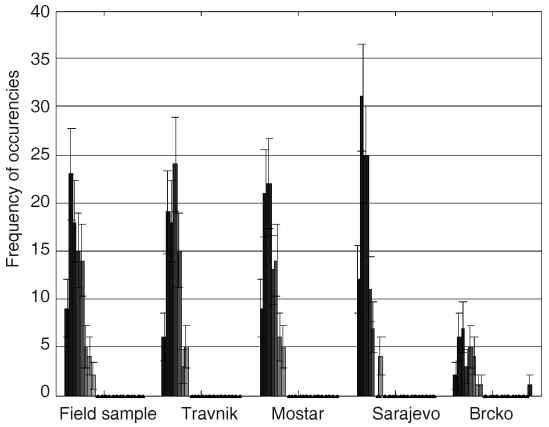

Figure 6. Histograms of ambient dose equivalent rates for different soil samples in the test field

Table 1. The soil sample components and bulk density of soils in the test field [6]

Soil components	Sample Brcko	Sample Travnik	Sample Mostar	Sample Sarajevo	Sample test field
Clay [%]	4.6	2.1	2.3	5.9	4.3
Silt [%]	23.5	16.6	15.4	18.5	39.4
Sand [%]	70.7	33.8	33.4	75.6	56.3
Gravel [%]	1.2	47.5	48.9	0.0	0.0
Bulk density	2.00	1.87	2.11	2.05	2.03

Table 2. Basic parameters of descriptive statistics for the measured values of ambient dose equivalent rates with the survey meter, at 1 m distance from the ground, in the test field

Descriptive statistics	Sample Brcko	Sample Travnik	Sample Mostar	Sample Sarajevo	Sample test field
Mean [μSvh^{-1}]	0.0497	0.0572	0.0544	0.0426	0.0548
Median [μSvh^{-1}]	0.04	0.06	0.05	0.04	0.05
Standard deviations [μSvh^{-1}]	0.0040	0.0032	0.0034	0.0029	0.0036
Minimum [μSvh^{-1}]	0.01	0.01	0.01	0.01	0.01
Maximum [μSvh^{-1}]	0.14	0.13	0.13	0.13	0.20

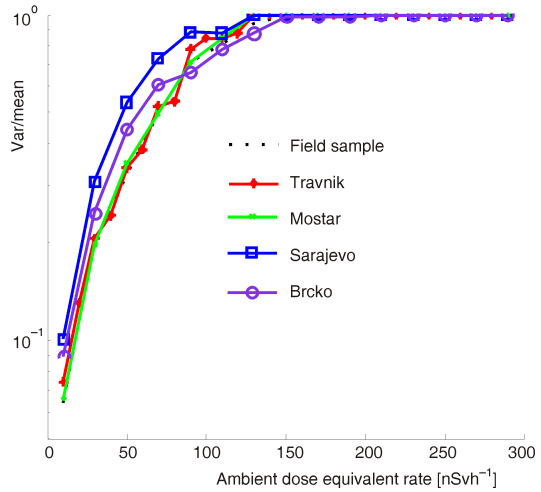

Figure 7. The results of the variance to mean ratio for experimental ambient dose equivalent rates for different soil samples in the test field

Brcko soil samples are somewhat different compared to the other ones, but they are not significantly different at significance level of 0.05.

The results of the variance to mean ratio, for experimental ambient dose equivalent rates for different soil samples in the test field, indicate that the slopes of all curves, given in fig. 7, are similar, although the slopes of curves for the Sarajevo and Brcko samples slightly deviate from the others, showing that terrestrial radiation from both samples is somewhat different compared to the others.

The results obtained in the first series of measurements with RADIAGEM^{TM} 2000 at 1 m distance from each sample show that there is no significant difference at significant level of 0.05 between ambient dose equivalent rates from different samples, but it can be noticed that there was a slight deviation for the samples with similar compositions, compared to other ones, even when the survey meter was located at 1 m from the ground.

The second series of the measurements was performed with the survey meter placed on the soil samples in the test field. Each measurement by RADIAGEM^{TM} 2000 was carried out for one minute and then the highest value during that time was taken as in the previous set of measurements. We performed 50 measurements for each sample in the test field.

The results of basic statistical analysis of ambient dose rates, obtained for soil samples, using the survey meter on the ground, are given in tab. 3. The mean value of ambient dose equivalent rates for all samples is 0.0794 0.0078 Sv/h, in the range from 0.01 to 0.36 Sv/h. It can be noticed that the mean value of ambient dose equivalent rate for all the samples, when the survey meter was on the ground, is higher than in the previous series of measurements, when the instrument was at 1 m distance from the ground.

The results of one-way ANOVA test are given in fig. 8. P-value of 0.0004 is close to zero, which suggests that at least one sample mean is significantly different from means of the other samples.

Histograms of the experimental data with uncertainties obtained in the test field, with the survey meter placed on the ground, are given in fig. 9. It can be noticed that deviations between TGR from different soil

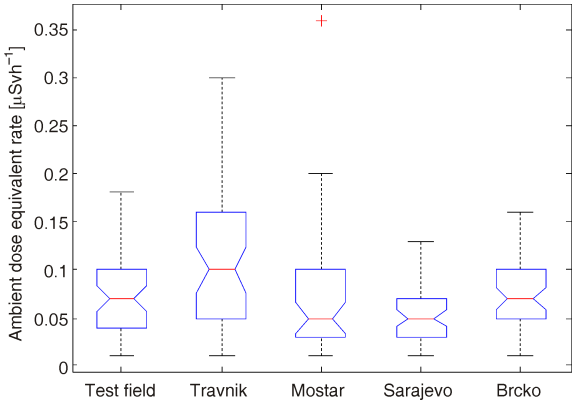

Figure 8. The results of a one-way ANOVA test of experimental data obtained from RADIAGEM^{TM} 2000 placed on the ground

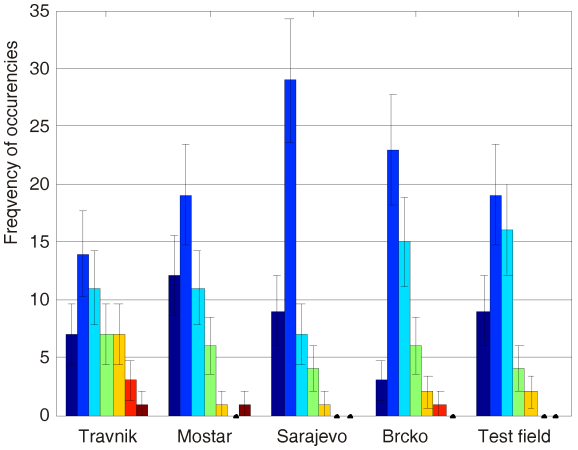

Figure 9. Histograms of the TGR experimental data obtained with the survey meter placed on the ground in the test field

Table 3. Basic parameters of descriptive statistics for the measured values of ambient dose equivalent rates 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 [μSvh^{-1}]	0.0832	0.1090	0.0712	0.0604	0.0734
Median [μSvh^{-1}]	0.07	0.10	0.05	0.05	0.07
Standard deviations [μSvh^{-1}]	0.0070	0.01	0.0089	0.0061	0.0065
Minimum [μSvh^{-1}]	0.01	0.01	0.01	0.01	0.01
Maximum [μSvh^{-1}]	0.23	0.30	0.36	0.22	0.18

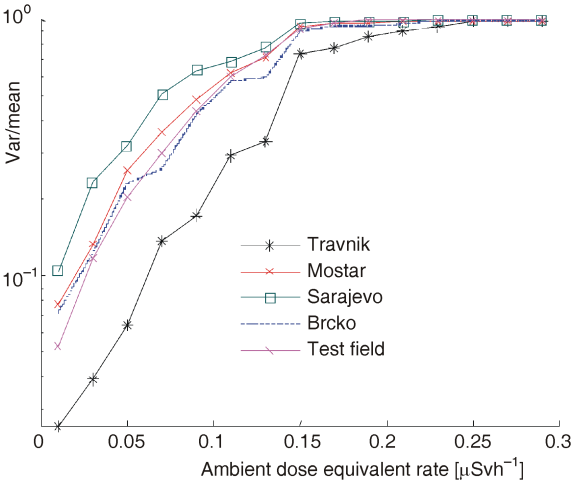

Figure 10. Variance to mean ratio for TGR experimental data obtained with the survey meter placed on the ground in the test field

samples are more pronounced than in the first series of measurements, at the same significance level of 0.05.

Figure 10 represents variance to mean ratio for TGR experimental data and also confirms that the differences between the relative TGR are larger when the survey meter was placed on the ground.

Analysis of the results obtained have shown that the second series of the measurements enabled to us observe the larger differences between the TGR from different soil samples in the test field, compared to the first series of the measurements.

CONCLUSIONS

This paper deals with assessment of TGR relative contribution in the test field, due to different soil samples from a few locations close to the minefields in Federation of Bosnia and Herzegovina. Measurements of ambient dose equivalent rates in the test field were carried out by RADIAGEM^{TM} 2000 portable survey meter, whose performances and sensitivity were investigated in the laboratory conditions. The survey meter is designed for measurements of ambient dose equivalent rate. However, ambient dose equivalent rate $H^*(10)$ cannot be physically measured in the field since the conditions of definition cannot be constructed during in situ measurements and it is commonly referred to as "air absorbed dose". It was demonstrated in the laboratory conditions that the radiation survey meter is suitable for natural radiation measurement, as well as for survey of contaminated surfaces by radioactive material of low activity.

The RADIAGEM^{TM} 2000 survey meter is designed for fast survey and measurements of dose rate with less accuracy, so that it is suitable for assessment of dose rate in comparison with the devices including an ion chamber or a proportional counter, which can provide more accurate results of dose rate measurements.

The first set of measurements of ambient dose equivalent rate in the test field was performed at 1 m above the soil samples. All the samples were exposed to the same cosmic radiation, so that there was a possibility to asses a relative contribution from TGR due to soil samples of various composition. The results obtained confirmed that there was no statistically significant difference between TGR from various soil samples, although the results have shown that there was a slight difference between TGR for the Sarajevo and Brcko samples whose composition is similar and somewhat different compared with the other ones in the test field.

The other set of measurements was done with RADIAGEM^{TM} 2000 which was placed on each soil sample individually, to take measurements on the ground. We conducted 50 measurements over one minute for each sample with the radiation survey meter and then, the highest value during that time interval was taken. The results obtained have shown that it was possible to assess the relative contribution of TGR at statistically significant level from different soil samples in the test field.

The results of this investigation could be useful for a few reasons. Since multi-sensor landmine detection systems are the most promising systems for more efficient demining, incorporation of information about the local soil environment, including the terrestrial background radiation, into the integrated sensor system, could contribute to databases for such detection systems. The results of this study could be also of public interest in the examined area, especially for workers active in demining of minefields and other people who spend more time outdoors. Apart from this, the experimental results of this radiological study could be useful for assessment of potential contamination of an area by the man made radioactive nuclides, taking into account that detection of a weak or distant radioactive source strongly depends on the background level which mainly comes from terrestrial radiation.

In the framework of future work it was planned to expand measurements of ambient dose equivalent rates at different locations, at various altitudes above sea level in the Tuzla Canton in order to perform detailed mapping of absorbed dose rate in air in the Tuzla Canton.

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AUTHORS' CONTRIBUTIONS

S. Avdić and I. Gazdić performed the experiment in the laboratory while M. Musić and B. Pehlivanović conducted measurements in the test field. All the authors participated in analysis and discussion of the re-

sults presented, and in preparation of figures, tables and text of the manuscript.

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ПРОЦЕНА РЕЛАТИВНОГ ДОПРИНОСА ТЕРЕСТРИЈАЛНОГ ПОЗАДИНСКОГ ЗРАЧЕЊА У ТЕСТ ПОЉУ КОРИШЋЕЊЕМ УРЕЂАЈА RADIAGEM^{TM} 2000

Ова студија фокусирана је на радиолошка испитивања терестријалног зрачења у тест пољу са узорцима тла из неколико минских поља у Федерацији Босне и Херцеговине. Мерења амбијенталне јачине дозног еквивалента, уобичајено назване "јачина дозе у ваздуху", извршена су у тест пољу лоцираном у Тузланском кантону помоћу портабл уређаја RADIAGEM^{TM} 2000, који се заснива на енергетски-компензованом ГМ бројачу. Перформансе уређаја су тестиране у лабораторијским условима са тачкастим гама изворима. Пошто су сви узорци тла у тест пољу били изложени истом космичком зрачењу, постојала је могућност процене релативног доприноса терестријалног зрачења услед узорака тла различитог састава. Једна серија мерења извршена је уређајем RADIAGEM^{TM} 2000 на један метар удаљености од сваког узорка, и основни статистички параметри показали су да не постоји значајна разлика између терестријалног зрачења из различитих узорака тла. Други сет мерења извршен је помоћу истог уређаја који је био постављен на тло у тест пољу. Обрада експерименталних података показала је да је могуће проценити разлике између релативног доприноса терестријалног позадинског зрачења из појединачних узорака тла. Резултати истраживања су од вишеструке користи и јавног интереса.

Кључне речи: RADIAGEM^{TM} 2000, мерач брзине дозе, терестријално гама зрачење, узорак тла, минско поље