11TH INTERNATIONAL SCIENTIFIC CONFERENCE
ON DEFENSIVE TECHNOLOGIES
OTEH 2024
Serbia, Tara, 9-11 October 2024

DETERMINATION OF NATURAL BACKGROUND RADIATION IN AN URBAN AREA AS AN ASPECT OF NUCLEAR SECURITY DETECTION ARCHITECTURE: AN EXAMPLE FROM THE CITY OF KRUŠEVAC, SERBIA

MILAN TANIĆ
Serbian Radiation and Nuclear Safety and Security Directorate, Belgrade, milantanic@yahoo.com

DENIS DINIĆ
University of Defense Belgrade, Military Academy, denis.dinic@yahoo.com

STEVAN STUPAR
Military Technical Institute, Belgrade, stevan.stupar13@gmail.com

Abstract: *The potential consequences of a nuclear security event could be catastrophic; therefore, all appropriate measures should be taken to prevent them. Detection, as one of nuclear security's functions, involves recognizing criminal or unauthorized acts with nuclear security implications, or measurements indicating the unauthorized presence of nuclear or other radioactive material at associated facilities, activities, or strategic locations. Determining natural background radiation in advance for such locations can certainly enhance the effectiveness of nuclear security detection architecture. In this research, measurements of natural background radiation were conducted at 324 points evenly distributed throughout the City of Kruševac, Serbia, including locations and objects most vulnerable to exploitation by potential adversaries. The ambient dose equivalent rate was determined using a handheld radioisotope identification device based on scintillation gamma spectroscopy and mapped using geostatistical software. The measured dose rates fell within the expected ranges for Serbia, as well as for the broader region and worldwide. No orphan sources were detected. Statistical tests indicated a significant difference in dose rate values between paved and unpaved urban surfaces. Furthermore, the most common false positives in radioisotope identification were ascertained. It is concluded that utilizing the methodology applied in this work for collecting readings and spectra on natural background radiation proved to be a cost-efficient means of facilitating the assessment of alarms or alerts, as well as detecting the presence of suspicious or unauthorized nuclear or radioactive material in the environment.*

Keywords: *Nuclear security, material out of regulatory control, radioisotope identification device, gamma-ray spectroscopy, alarm.*

1. INTRODUSTION

The properties of nuclear and other radioactive materials have many legitimate, useful, and beneficial applications in medicine, energy production, research, industry, agriculture, etc. These materials are highly regulated and strictly controlled. However, due to their widespread use, nuclear and radioactive materials are also susceptible to being exploited for security violations. Nuclear security is defined as the prevention of, detection of, and response to, criminal or intentional unauthorized acts involving or directed at nuclear material, other radioactive material, associated facilities, or associated activities where those substances are used [1]. A nuclear security event is an event that may potentially or actually have an impact on nuclear security. Such events encompass a broad spectrum of activities, including unauthorized removal (illegal taking), illicit trafficking, unauthorized sale or transfer of nuclear or other radioactive material, sabotage of nuclear or other radioactive material or associated equipment, or other malicious use of nuclear or other radioactive material, including cyber-attacks. Therefore, they must be addressed from a security standpoint [1].

While a regulatory framework related to nuclear security exists in the Republic of Serbia and all relevant stakeholders, i.e. competent authorities, have been identified, there is a lack of knowledge and awareness regarding nuclear security issues. Therefore, certain terms need to be further elaborated.

Regarding nuclear security issues, the key points involve malicious acts and materials outside regulatory control (MORC). MORC refers to the absence of direct control over material by an authorized person as mandated by regulatory requirements. This occurs in situations where nuclear or other radioactive material is present without appropriate authorization or in quantities that should be under regulatory oversight, but such control is absent due to failure or non-existence of regulatory measures [2]. Real-life examples of MORC include incidents such as lost in transit, illicit trafficking, theft, and orphan sources.

Corresponding author: M. Tanić;
E-mail: milantanic@yahoo.com
DOI: 10.5937/OTEH24093T

A malicious act is defined as an act or attempted unauthorized removal of nuclear material or radioactive material [3, 4] or sabotage, with the intent to cause death or physical injury to any person, material damage to any property, or damage to the environment [4]. An individual performing or attempting to perform a malicious act is an adversary [5].

A significant risk in nuclear security is the potential for adversaries to use nuclear or other radioactive material to create devices that expose people to radiation (RED, radiation exposure device), disperse radioactive material into the environment (RDD, radiation dispersion device), or even create a nuclear explosion (IND, improvised nuclear device) [6]. The potential consequences of a nuclear security event, particularly those involving RED, RDD, and IND, could be catastrophic. These events typically result in four main types of consequences: health, economic, environmental, and societal [1].

Prevention, detection, and response are the main nuclear security functions that must be in place to counter potential malicious acts. Prevention measures aim to deter adversaries from attempting or committing malicious acts, detection measures aim to discover such attempts or acts, and response measures are designed to address malicious acts that have already occurred or in progress. Considering MORC, detection measures rely on use of radiation detection instruments (technical detection capabilities), operation information, and medical surveillance for suspicious radiation injuries or illnesses (non-technical detection capabilities) [7].

The Nuclear Security Detection Architecture (NSDA) refers to the comprehensive network of nuclear security systems and measures, established within a suitable legal and regulatory framework, essential for executing a national strategy to detect nuclear and other radioactive MORC. The NSDA plays a crucial role in safeguarding individuals, property, society, and the environment from the adverse effects of nuclear security events by improving a state's ability to monitor and regulate the movement of nuclear and other radioactive materials [8]. However, given that states have limited resources, they should employ methods to identify which nuclear security measures will be most effective in reducing risk. The effectiveness of specific detection measure is evaluated and prioritized using a risk-informed approach [6]. Determining the natural background radiation in the area of identified targets of potential exploitation should certainly be included by competent authorities in a risk-informed approach, since one of the very first signs of a nuclear security event involving the dispersion of nuclear or radioactive material would be dose rate values above the natural background level in the affected area.

Target within a nuclear security event implies nuclear material, other radioactive substances, associated facilities, activities, or other locations and objects vulnerable to exploitation by nuclear security threats, including major public events, strategic locations, sensitive information, and assets [1]. Urban areas, due to their concentration of numerous locations that may be targeted by nuclear security threats and the potential consequences for people, property, and the environment, are identified as having the highest probability of experiencing a nuclear security event. These targets include buildings, monuments, and places of symbolic importance such as government buildings, private institutions, palaces, museums, religious sites, and locations of cultural or political significance. Additionally, urban targets encompass transport infrastructure, critical infrastructure like power generation facilities, water treatment plants, bridges, and information systems that serve large populations, as well as dense population areas and major public events.

Since the initial assessment of an alarm or alert is the most crucial detection step, having information on the radiation levels in and around potential targets beforehand is essential for the successful and timely indication of a nuclear security event. This becomes even more important considering that natural background radiation exists due to cosmic rays, cosmogenic and terrestrial radionuclides, making it difficult to identify specific radiation signals in an environment with many benign radiation sources. Moreover, background radiation levels often vary throughout the day, typically slightly increasing during daylight hours and decreasing in the evening.

Instruments detect elevated radiation levels by comparing the ambient radiation against known background levels. A significant spike in radiation triggers an alarm. Radiation detection instruments used for nuclear security purposes generally measure gamma and neutron radiation. Nuclear and other radioactive materials emit radiation as a consequence of radioactive decay. However, different materials vary in the amount and type of ionizing radiation they emit, resulting in differences in the shape and strength of the instrument's signal.

Radiation detection instruments vary in size, mobility, capabilities, and features. For nuclear security purposes, they can be roughly divided into several categories: personal radiation detectors (PRD), portable radiation scanners (PRS), fixed radiation portal monitors (RPM), and hand-held instruments. Hand-held instruments are further classified into specific groups: gamma search devices, neutron search devices, and radioisotope identification devices (RID) [1, 7, 9]. RIDs locate and identify radionuclides present in the examined media. They are typically handheld but can also be worn as backpacks or mounted on vehicles. These instruments are capable of collecting and analyzing energy spectra to identify isotopes. Additionally, they can be used as dose rate meters, survey instruments, and to locate nuclear and other radioactive materials. Consequently, RIDs are widely used by nuclear security officers after an alarm from a PRD or RPM to confirm the alarm and identify the source. Due to their versatility, characteristics, and wide availability, RID devices are ideal for measuring natural background radiation for nuclear security purposes.

The literature review revealed that the consideration of natural background radiation in urban areas as part of NSDA for cities in Serbia has not yet been undertaken so

far. Therefore, the objectives of this study were: 1) to determine natural background radiation by collecting gamma-ray spectra and measurement of ambient dose equivalent rates in the area of the City of Kruševac, Serbia, using a proven RID; 2) to spatially map the collected data; and 3) to identify the most common challenges associated with radiation detection using instruments, in order to understand the limitations of the selected detection device when integrating these measurements into NSDA.

2. MATERIALS AND METHODS

Kruševac is a midsized city in central Serbia, serving as the administrative center of the Rasina District. With a population of 53,746 according to the 2022 Census and covering a total area of approximately 11.3 square kilometers, it represents an average Serbian city. Kruševac is a vital hub for local industries and commerce, significantly contributing to regional economic development. Its strategic location ensures easy access to major cities in Serbia, making it a key transit point and regional center, including the possible transport of radioactive sources. Kruševac was the medieval Serbian capital and holds great historical importance and heritage. Given these factors, the city contains numerous potential targets that could be exploited by adversaries in the context of nuclear security. There are no nuclear or associated facilities within the city's borders. Among authorized radiation practices, medical ones are predominant. One of the measuring stations equipped with instrument that continuously monitors air radioactivity, as part of the national early warning system for nuclear or radiological emergencies, is located in Kruševac. This station is also integrated into the European Radiological Data Exchange Platform (EURDEP).

All measurement were carried on using a hand-held RID ThermoScientific RIIDEye M-GN, equipped with a 2" × 2" NaI(Tl) crystal scintillation detector. The intrinsic efficiency for the ^{137}Cs 662 keV photo-peak was 26.5 %. The resolution for the same photopeak was experimentally determined to be 8.31 %. This radiation spectrometer was calibrated to identify gamma-rays and radionuclides between 0.25 keV and 3 MeV. Operating voltage of integral high voltage supply was 400 V. The settings for the amplifier were as follows: coarse gain 1, fine gain 1.29, shaping time 1.28 μs, and negative polarity. The lover and upper level discriminators (LLD and ULD) were set 0.80 % and 100 %, respectively, expressed as a percentage of the full spectrum below/above spectral information was not captured. The zero offset was 0.1445 % of the spectrum. High voltage, gain and zero offset were adjusted by coarse calibration using an unshielded 37 kBq ^{137}Cs source, performed daily when sampling was carried on. Fine energy calibration was factory set up. Conversion gain (total number of channels) was 256. RID used in this research are specifically designed for search missions and the identification of radionuclides and nuclear materials. The isotope identification algorithm employs quadratic compression conversion (QCC), which addresses challenging peaks by increasing the number of channels and concurrently compressing high-energy peaks to enhance the signal-to-noise ratio. The system is constructed in accordance with ANSI 42.34 standards, and the data is provided in the ANSI 42.42 spectral report format, which is compatible with any PC-based software for review

All measurements of the ambient dose equivalent rate in the air $\dot{H}^*(10)$, were taken at a height of 1 m from the ground. The sampling time was 300 s. Sampling time was calculated based on a desired 1 % uncertainty of the gamma count rate at a 95 % confidence level. An initial assessment of the gamma count rate at ten random locations showed that an average value of 134 cps (counts per second) could be expected. Measurements were carried on from March to May 2024, during daylight. The similar methodology was utilized in the research with similar design [10].

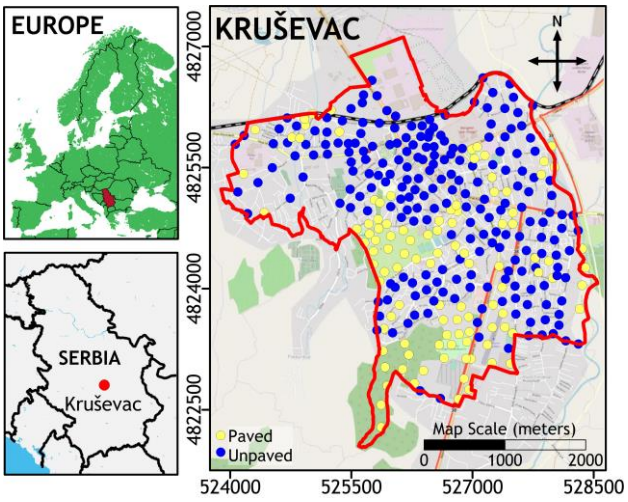

Figure 1. Map of the study area with denoted measurement points

A total of 324 measurement points were randomly selected to evenly cover the entire territory of the City of Kruševac, with sampling density of approximately one point per 40,000 m^2. This included all locations critical from a nuclear security perspective, such as the City Hall, headquarters of governmental and self-governmental institutions, green markets, sports centers, schools, main squares, most visited parks, churches, and the most occupied parking places. One-third of all measurement points were unpaved. All measurement points were freely and easily accessible to the public. Areas with restricted access, such as military facilities and industrial complexes, were excluded from the research. The coordinates for each measurement point were determined by a GPS device with a precision of ± 3 m, and using GeoSrbija, a portal of the Serbian Geodetic Authority. A map of the study area including the locations of all measurement points is presented in Figure 1.

Statistical analyses were performed using the IBM SPSS Statistics v.20 software package. The spatial presentation of the results was done using Surfer Golden Software 12, with inverse distance weighting (IDW) used as the

interpolation method. This method assumes that the influence of the variable decreases with the increase in distance from the point where the value of the variable is known.

3. RESULTS AND DISCUSSION

Descriptive statistics of ambient dose equivalent rate (hereinafter: dose rate) determined at all measurement points in this work are listed in Table 1. The dose rate values ranged from 10.09 to 103.68 nSv h^{-1} with an average of 55.52 nSv h^{-1}. The mean dose rate obtained in this study was considerably lower than the mean annual dose rates in the Republic of Serbia in 2022, which varied from 105 to 137 nSv h^{-1} [11].

Background radiation under normal conditions originates from cosmic radiation, as well as natural and anthropogenic radionuclides in the soil, air, and ground surface. Radiation emitted from primordial terrestrial radionuclides represents the main component [12]. NaI scintillator detectors, based on their features, measure terrestrial radiation very well (103 % response) but only 30 % of secondary cosmic radiation [13]. Therefore, the obtained mean dose rate value is in good accordance with the worldwide average outdoor absorbed dose rate of 56 nGy h^{-1}, which corresponds to 41 nGy h^{-1} when taking into account a conversion coefficient of 0.7 Sv Gy^{-1} [12].

Table 1. Descriptive statistic of the ambient dose equivalent rate $\dot{H}^*(10)$ (in nSv h^{-1}, unless otherwise indicated)

Parameter	$\dot{H}^*(10)$	Parameter	Value
Mean	55.52	St. deviation	21.05
Median	48.50	*CV*/%	37.91
Minimum	10.09	Skewness	0.52
Maximum	103.68	Kurtosis	-0.80

The dataset distribution was tested using the Shapiro–Wilk test, and it showed no normal distribution ($p = 0$), which is expected given the nature of environmental measurements and the large sample size. Data were tested for outliers according to Grubbs' criteria, and no outliers were detected.

Dose rates may strongly vary over short distances, and it is important to detect these local changes as clearly as possible. The measured doses varied according to the cover of the particular location, as well as the geological background, soil types, and the types of building materials used in buildings or other constructions in close proximity to the particular measurement point (hereinafter: MP).

There were two groups of MPs based on their cover: 1) paved and 2) unpaved. The unpaved MPs had no pavement, tiles, or other types of artificial cover and often featured vegetation on the surfaces. The type of MP at a certain location in the study area was chosen based on the most dominant type of cover and the authors' judgment of where residents would have the highest occupancy time outdoor. The spatial distribution of paved and unpaved MPs is shown in Figure 1. For the 106 unpaved MPs, the dose rate values ranged from 10.09 to 102.59 nSv h^{-1} with a mean of 79.32 nSv h^{-1}. In contrast, for the 218 paved MPs, the dose rate values ranged from 12.79 to 103.68 nSv h^{-1}, but the average value was notably lower at 43.95 nSv h^{-1}. A Box-Whisker plot of the dose rate values for the total number of MPs, as well as for the two groups of MPs separately, is provided in Figure 2.

The dose rate values obtained for unpaved MPs are in good agreement with the values obtained at the automatic measuring station in Kruševac in the sampling period (approximately 80 nSv h^{-1}), which is also installed at locations with unpaved grassy surface. Results of continuous monitoring can be accessed via the EURDEP platform (https://remap.jrc.ec.europa.eu/Advanced.aspx, measuring station RS31156).

The coefficient of variation (*CV*) is the most obvious statistical parameter for describing data variability. This factor taken into account all MPs was 37.91 %, indicating uneven distribution of dose rate values across the study area, which may suggest anthropogenic influence on radionuclide specific activity contributing to radiation levels. However, further examination of the two datasets showed that their standard deviations were quite low, resulting in low *CV* values of 17.60 % and 18.02 % for unpaved and paved MPs, respectively. These findings clearly indicate no anthropogenic influence on dose rate values in the study area.

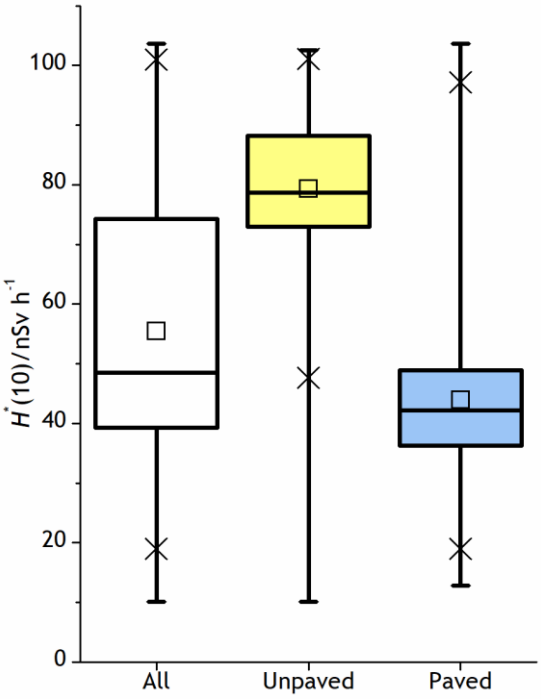

Figure 2. Box (25th-75th quartile) and Whisker (min-max) plot of the ambient dose equivalent rate (square represents mean values, and crosses 1st and 99th percentile)

Bearing in mind that dataset was not normally distributed, but the sample size was large enough ($n = 324$), an independent samples *t*-test was conducted to compare the

means of the ambient dose equivalent rate between two groups of measurement points, those with paved surfaces and those with unpaved surfaces. Levene's test for equality of variances indicated that variances of the two groups were assumed equal ($p = 0.372$). The t-test revealed significant differences between the two groups ($t = 23.097$, $p = 0$), with a mean difference of 35.37 nSv h^{-1}. The 95 % confidence interval for the mean difference ranged from 32.36 to 38.38 nSv h^{-1}. Based on eta square value ($\eta^2 = 0.55$), the effect of ground cover on the ambient dose equivalent rate was considered large.

An isodose map was produced to represent the spatial variability of the dose rates due to natural background radiation and is presented in Figure 3.

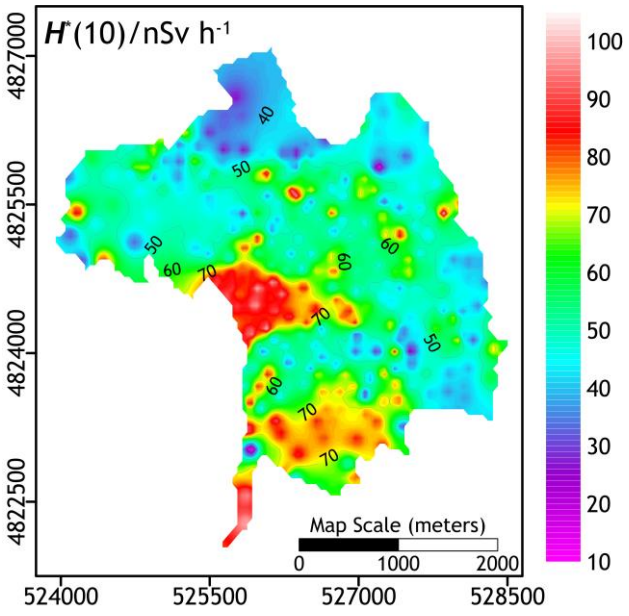

Figure 3. Spatial distribution of ambient dose equivalent rate depicted using IDW to a power as the gridding interpolation method

As can be noticed, depending on the color and its intensity, which is proportional to the dose rate value, two regions can be clearly delineated. The first region is located in the south of the study area, where the lowest dose rates were measured and interpolated. This is an industrial zone with no vegetation and virtually no unpaved surfaces. The second region, which spreads to the south and southwest of the study area, is where the highest dose rates were measured. This region includes the largest city park (Memorial Park "Slobodište") and a dense deciduous forest. Moreover, this is the least urbanized part of the city.

Primordial natural radionuclide ^{40}K, along with radionuclides belonging to the ^{238}U (^{226}Ra) and ^{232}Th radioactive families, are the most dominant radionuclides in soil. Potassium-40 was identified at 77% of MPs, while ^{226}Ra and ^{232}Th were identified at 11 % and 5 % of MPs, respectively. The MPs where the last two radioisotopes were identified were those where the highest dose rates were determined. The majority of ^{40}K and ^{232}Th positive identifications were recorded at unpaved MPs. Conversely, ^{226}Ra was recorded above paved MPs with granite tiles or in the close vicinity of buildings. Therefore, one can conclude that the ^{226}Ra identification is mostly a consequence of higher ^{238}U content in building materials.

False positive (hereinafter: FP) is defined as the situation when the instrument identified one or more radionuclides that were not present as being present without making any correct identification other than ^{40}K [14].

The existence of FPs was verified by additional spectrum acquisition at measurement points (MPs) where unexpected radionuclides were identified. That measurement was taken using a 2" × 2" NaI(Tl) scintillation detector (ORTEC 905-3) with the ScintiPack Photomultiplier Base (Model 296) coupled with a digiDART portable multichannel analyzer. Spectra were collected with a 512 conversion gain. The obtained spectra were later processed and inspected using ScintiVision 32 software. Each measurement (spectrum acquisition) lasted 600 seconds.

The most frequent radionuclides other than natural ones, that were identified were: ^{133}Xe and ^{109}Cd (26), ^{103}Pd (6), ^{192}Ir and ^{88}Y (5), ^{238}Pu and ^{239}Pu (3), ^{233}U (2), ^{54}Mn and ^{57}Co (1). The number of MPs where each particular radionuclide was identified is given in parentheses. It is worth mentioning that all of them were identified with a low level of confidence, and mesured dose rates were not high. Further verification of the mentioned isotopes confirmed that they were not present in the environment, so their identifications were FPs. Therefore, it can be concluded that neither MORC nor orphan sources were detected in the study area. Given that some of listed radionuclide appeared in the same spectrum, the overall FP rate was 19 %. Similar FP rates were found in other research evaluating the features of hand-held RIDs [14].

All of the FPs are artificial radionuclides. Since there were no authorized radiation practices in Kruševac involving these radionuclides, their presence was considered unexpected. The most probable reasons for such an FP rate were short counting time, a limited radionuclide library, and the QCC spectrum analysis algorithm specifically designed for nuclear security purposes, especially for the identification of special nuclear material. Moreover, all of them, except ^{192}I, ^{88}Y, and ^{54}Mn, emit low-energy gamma rays with low intensity. Further discussion of FPs is beyond the scope of this paper.

4. CONCLUSION

This research is the first of its kind in the study area. The level of natural background radiation was determined for the entire territory of the City of Kruševac. The authors concluded, based on the average values of the dose rate, that these values are below the background levels for Serbia. Paving of public roads, sidewalks, and other urban areas was identified as a major contributor to the reduction of dose rates at various points in the study area. Although the range of the dose rates was similar in the

two groups of MPs, their mean values differed by a factor of 1.80. Nevertheless, the values of the ambient dose equivalent rate for unpaved surfaces were in good agreement with background levels for Serbia.

The knowledge of natural background radiation and particularly the availability of maps of dose rates due to background radiation are important in order to detect artificial radioactive contamination after a nuclear security event and to evaluate its impact on the population.

Determination of natural background radiation in advance for urban environments is one of the activities that certainly can enhance the effectiveness of NSDA by contributing to capacities to monitor and control the movement of nuclear and other radioactive material. This is particularly important because if nuclear security event had occurred, most measurements would have been taken by responders who are non-technical personnel and will need some kind of "standard" to compare and interpret the obtained results. Therefore, this process may serve as an auxiliary component of technical support for detection within the framework of NSDA.

This research was conducted as a preliminary study. Further investigation will focus on increasing the measurement point density to cover the entire city, up to one point per 20,000 m^2, employing additional radiation equipment relevant to nuclear security (e.g. PRDs), measuring additional quantities (gross count rate, gamma, and neutron count rate), conducting indoor measurements (in dwellings, schools, and other buildings), performing those measurements in different seasons to assess temporal variability of the natural background, conducting geostatistical analysis of the obtained results, and assessing the radiation risk for the population under normal circumstances.

Acknowledgements

This work was by Serbian Ministry of Defense and Serbian Ministry of Education, Science and Technological Development, Grant No 451-03-66/2024-03/200325.

References

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, *Objective and Essential Elements of a State's Nuclear Security Regime, Nuclear Security Series No. 20*, IAEA, Vienna, 2013.

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, *Nuclear Security Recommendations on Nuclear and Other Radioactive Material Out of Regulatory Control, Nuclear Security Series No. 15*, IAEA, Vienna, 2011.

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Security Recommendations on Radioactive Material and Associated Facilities, Nuclear Security Series No. 14, IAEA, Vienna, 2011.

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, *Security of Radioactive Material in Use and Storage and of Associated Facilities, Nuclear Security Series No. 11-G*, IAEA, Vienna, 2019.

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, *Security of Radioactive Material in Use and Storage and of Associated Facilities, Nuclear Security Series No. 8-G (Rev. 1)*, IAEA, Vienna, 2020.

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, *Risk Informed Approach for Nuclear Security Measures for Nuclear and Other Radioactive Material out of Regulatory Control, Nuclear Security Series No. 24-G*, IAEA, Vienna, 2015.

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Detection in a State's Interior of Nuclear and Other Radioactive Material out of Regulatory Control, *Nuclear Security Series No. 47-T*, IAEA, Vienna, 2024.

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, *Nuclear Security Systems and Measures for the Detection of Nuclear and Other Radioactive Material out of Regulatory Control, Nuclear Security Series No. 21*, IAEA, Vienna, 2013.

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, *Nuclear Security Systems and Measures for Major Public Events, Nuclear Security Series No. 18*, IAEA, Vienna, 2012.

[10] AMARAL,R.D.S., et al.: *Environmental Ionizing Radiation Dose Outdoor in an Inhabited Area with a High Concentration of Urano-Phosphate in Northeast of Brazil*, Radiation Protection Dosimetry, 181(3) (2018) 181-189.

[11] SERBIAN RADIATION AND NUCLEAR SAFETY AND SECURITY DIRECTORATE: *The Annual Report on Public Exposure to Ionizing Radiation in the Republic of Serbia in 2022*, SRBATOM, Belgrade, 2023.

[12] UNITED NATION SCIENTIFIC COMMITTEE ON THE EFFECT ON IONIZING RADIATION, *Sources and Effect on Ionizing Radiation, UNSCEAR 2008, Report to the General Assembly with Scientific Annexes, Volume 1, Annex B*, United Nations, New York, 2010.

[13] VULETIĆ,V., et al.: *Comparison of Gamma Dose Rate Values in Air Measured by GM Counters, Ionization Chambers, and Thermoluminescence Dosimeters*, in Proceedings of the XXV Symposium of the Radiation Protection Society of Serbia and Montenegro, Kopaonik, pp. 289-292, 2009.

[14] PIBIDA,L., UNTERWEGER,M., KARAM,.R.: Evaluation of Handheld Radionuclide Identifiers, Journal of Research of the National Institute of Standards and Technology, 109(4) (2004),