RADIATION PORTAL MONITORS RESPONSE TO GAMMA RADIATION AND TO THE DETECTION CAPABILITY OF ORPHAN RADIOACTIVE SOURCES: CONTRIBUTION OF THE STRASS PROJECT

by

Alexandros CLOUVAS [1*]***, Fokion LEONTARIS*** [1]***, and Stelios XANTHOS*** [2]

[1] Department of Electrical and Computer Engineering, Aristotle University of Thessaloniki, Thessaloniki, Greece
[2] Department of Industrial Engineering and Management, International Hellenic University, Thessaloniki, Greece

Scientific paper
https://doi.org/10.2298/NTRP2003244C

Radiation portal monitors are commonly used to detect and intercept unauthorized movement of nuclear and other radioactive materials at country borders. A total of twelve double-pillar portal monitors are present at the Greek-North Macedonian border, each containing two polystyrene scintillating detectors per pillar. Spatial and spectral response testing of the scintillating detectors to gamma radiation was performed by using different radioactive sources and comparing the measurement results with Monte Carlo simulations. A good agreement of the experimentally deduced activities of different point sources, needed for alarm triggering of the radiation portal monitors with Monte Carlo calculated values, was observed. Spectral results show no photopeaks in the spectra due to low resolution of these detectors. The broad peaks observed in the spectra correspond to the Compton edge. Measured spectra with a ^{137}Cs source placed directly on the scintillating detector, at several positions away from the photo multiplier tube, show an energy shift of the Compton edge towards lower energies, as the source is moving away from the photo multiplier tube. The energy shift is due to light transfer mechanisms within the scintillator volume and therefore, it is only observed in optical simulations and not in gamma-ray particle simulations.

Key words: radiation portal monitor, gamma radiation, orphan radioactive source, Monte Carlo simulation

INTRODUCTION

Nuclear terrorism is a global security challenge and cannot be addressed by any nation alone. Overcoming this challenge requires strong regional and international co-operation. European Member states, in co-operation with other countries and the International Atomic Energy Agency (IAEA), understand the importance of nuclear security and embrace the shared international responsibility to develop and promote systems and measures for the prevention of, detection of, and response to nuclear or other radioactive materials transportation out of regulatory control (Orphan Radioactive Sources) [1-3].

Radiation portal monitors (RPM) are commonly used to detect and intercept unauthorized movement of nuclear and other radioactive materials, both at country borders and within the States [4]. However, under certain circumstances, detection portals can fail to detect radiation (*e. g.* due to shielding). Therefore, improved detection devices, based on the best-performing technologies, are needed to provide improved and more reliable identification and quantification of contaminants. Implementing effective capabilities to detect and intercept unauthorized movement of nuclear and other radioactive materials, both at borders and within States, adds to global defences against nuclear terrorism. Since 2004, Greece has installed RPM in the *Evzoni* Greek border with the Republic of North Macedonia in order to prevent such kind of actions. At the border side of Republic of North Macedonia portable radiation detectors are used. In 2018, in the framework of the INTERREG IPA CBC Program *Greece – Republic of North Macedonia 2014-202*0, a two years project entitled *Safe Cross-Border Transportation of Hazardous Materials: Orphan Radioactive Sources* (STRASS), started. In the framework of this project, the response of the RPM to gamma radiation and to the detection capability of orphan radioactive sources, was studied in the *Evzoni* Greek-North Macedonia border.

---

[*] Corresponding author; e-mail: clouvas@eng.auth.gr

MATERIALS AND METHODS

The RPM in the *Evzoni* Greek border

In the Greek-North Macedonia border, twelve RPM have been installed since 2004 for detecting and intercepting unauthorized movement of nuclear and other radioactive materials. Each Radiation Portal has two pillars. The detection system is a TSA PM 700 AGN polystyrene portal monitor with two scintillating detectors per pillar, fig. 1. Each scintillating detector consists of a 79 cm high scintillating part (*i. e.*,15 cm 79 cm 3.8 cm) and a 10 cm high light guide (*i. e.*,15 cm 10 cm 3.8 cm), the latter being between the scintillator and the photo multiplier tube (PMT). The portal monitor, besides the scintillating detectors, contains an electronic circuit and a controller that handles data output and manipulation, linking the system to a display or a computer with appropriate software. Through the controller, the energy region-of-interest window of the detector can be altered in order to focus on the detection of certain radionuclides. At border crossings, a low energy window that favours the detection of ^{235}U is usually chosen. In the specific RPM, at the Greek- North Macedonia border, a 22-144 keV energy window represents the default energy window width value. In this work two energy windows were examined. The default one and the wider energy window from 22 keV up to 1595 keV.

Figure 1. Pillar of RPM (model TSA PM 700 AGN) in the Greek-North Macedonia custom; *1 – gamma detectors: two scintillating detectors per pillar, 2 – neutron detectors: two in each pillar, 3 – electronics*

Low system signal, recorded by the RPM, is due to natural gamma radiation background in the *Evzoni* Border or, because of possible gamma-ray emission from the cargo of a truck or a car passing through. It is very important to determine the natural gamma radiation background in the *Evzoni* Border and its variation (*e. g.* increase after rain due to deposition on the ground of ^{214}Pb and ^{214}Bi). An increase of the natural gamma radiation background will be considered by the RPM as possible radionuclide contamination of the cargo of the truck and it will trigger a false alarm. One of the problems encountered in the RPM is the problem of optimal sensitivity setting, without increasing the observed false alarms signal level. The increased flow of vehicles, particularly during the summer period, at the *Evzoni* Border makes it difficult to re-examine triggered alarms without obstructing traffic. For this reason the alarm level in RPM should be set at such a level to be able to reduce the number of false alarms without greatly reducing sensitivity. In addition, loads containing materials with natural radioactivity should, as far as possible, be recognized as innocent alarm and not as a real one.

The calculation of the threshold, over which the alarm will be triggered, is directly dependent on the background of natural radioactivity and is given by the formula

$$TL \quad \text{background} \quad c\sqrt{\text{background}} \qquad (1)$$

where *TL* is the alarm threshold in counts per second, background – background of natural radioactivity in counts per second, and *c* – the constant that determines the confidence level.

Obviously, the $\sqrt{\text{background}}$ indicates a Gaussian (normal) background distribution. In fact, the distribution of the background in counts per second is not a normal distribution, but it is very similar to it [5]. Constant *c* determines the confidence level of this distribution (*e. g.* for $c = 3$, we have a confidence level of 99.73 %). Once the integrated measured counts reach the threshold value (TL) for one second period, then the alarm is triggered. It is worth noting that most detectors perform a measurement every tenth of a second. The integrated counts for the one-second period corresponds to the 10 rolling sums of the 0.1 seconds measurements. Therefore, the influence of the background on the alarm threshold is significant. It is known that truck loads provide shielding from gamma radiation of the soil. The value of the background when a truck is between the flat detectors (*truckload* background) is lower from 10 % to 30 % or even lower than the *no-truck* background value [6]. An algorithm that takes this reduction into consideration will obviously have a higher sensitivity. Nowadays all RPM perform the before mentioned background correction.

Most RPM, as the ones at the Greek *Evzoni* border, use organic plastic scintillators to detect emitted gamma radiation. However, these detectors do not provide distinct spectroscopic information. For this reason, they usually operate as simple gross-count detectors. Alarms are often triggered by naturally occurring radioactive materials (NORM), and persons treated with medical radiopharmaceuticals. To reduce the number of these unwanted alarms, various advanced algorithms are considered. Most commonly used algorithms are the windowing algorithms [5] that are based on the calculation of the ratio between radiation intensity in a low-energy and a high-energy window of the observed scintillation spectrum. This ratio is different for NORM and artificial radionuclides, particularly special nuclear materials. This allows the detection of radioactive material, as well as providing a rough radionuclide identification.

Spatial response measurements

In order to test the scintillating detectors, spatial and spectral response gamma measurements were performed in combination with Monte Carlo simulations. The spatial response measurements were conducted with a ^{137}Cs source. The acquisition time was 10 seconds and the average value of counts was taken. The monitor collects the counts in 0.2 seconds intervals and the detector counts are updated every second. First, a background measurement was taken. Then, the point source was placed directly on the surface of scintillating detector, fig. 2, at several positions (15 cm, 20 cm, 30 cm, 40 cm, 50 cm, 60 cm, and 70 cm) away from the PMT. For each source position the count rate (counts per second – cps) displayed by the detector was recorded. The portal monitors were set to measure counts from 22 keV up to 1595 keV (total energy window). In addition, ^{137}Cs and ^{152}Eu point sources were placed at different distances up to 3 m away from the scintillating detector. This distance is equal to the half distance between the two pillars of the RPM. The background measurement was taken and subtracted from all the actual measurements, for all source positions. The aim of this experiment was to estimate the minimum activity of the source for alarm triggering of the RPM, under static conditions.

Spectral response measurements

The portal monitors' scintillating detectors are not constructed for spectroscopic analysis like gamma spectrometry detectors. In order to acquire spectra from the scintillating detectors, a multi-channel analyser and a laptop with the appropriate software had to be connected to the corresponding probe of the portal monitor's electronic circuit. This was achieved both by studying the portal monitor's circuit and choosing optimum software settings. The software used for the task was GENIE 2000 [7]. This software was built to acquire spectra primarily from HPGe detectors and not from plastic scintillators. Nevertheless, optimum software settings and suitable detector probes were found, and the measurements were completed successfully. The spectra were obtained with ^{137}Cs and ^{152}Eu point sources placed in different distances away from the middle of the panel. In addition, spectra were obtained with the ^{137}Cs source placed on the surface of the panel for different distances from PMT. As the measurements were performed in different days, a spectrum of the background was taken and subtracted from all the measured spectra in the specific day. The acquisition time for all the measured spectra was 300 seconds.

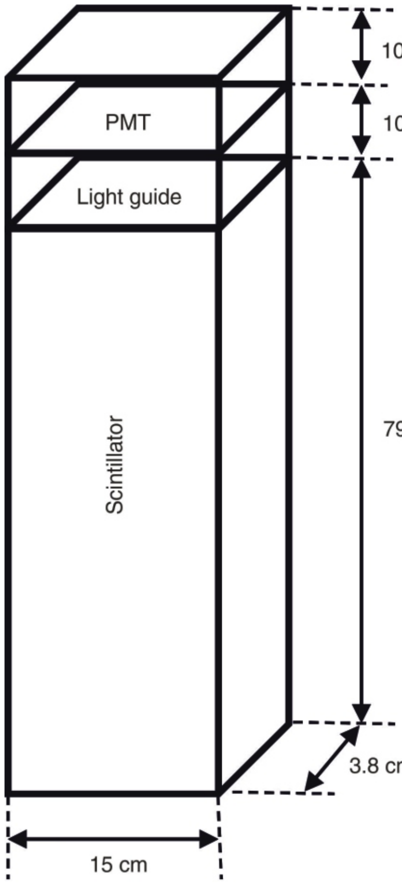

Figure 2. Schematic diagram of the scintillator detector; it consists of a 79 cm high scintillating part, a 10 cm high light guide, the latter being between the scintillator and the PMT

Monte Carlo simulations

Simulation of the scintillating detectors of the RPM at the Greek-North Macedonia border was carried out with a set of Monte Carlo simulations. The tool used, in order to simulate spatial response to gamma radiation of these detectors, was the MCNP code of the Los Alamos National Laboratory [8]. The user-supplied information required by MCNP contains information about specific items such as the geometry and the materials characterizing the environment that will be simulated, the source distribution of the radiation, and finally the type of the answers desired (*e. g.* energy distribution of photon flux in a given position). The simulated geometry is the one shown in fig. 2. The material of the scintillator is styrene polymer (polystyrene with a ratio of H: C = 1 and a density ρ = 1.05 gcm^{-3}). The Monte Carlo simulations were performed for a ^{137}Cs point source, positioned on the surface of the scintillator, at distances of 20, 30, 40, 50, 60, 70, and 75 cm from the PMT. An input file was generated for each source position. The tally used for the simulation was the standard f8 of the MCNP code (pulse height tally). Each simulation was done for 100-250 million particles, a number considered enough to give results with good statistics. The output extracted from the spatial response simulations was the counts for the total energy widow 22-1595 keV, normalized per starting photon. Besides the ^{137}Cs radiation source, Monte Carlo simulations were also performed with the MCNP code for ^{60}Co and ^{40}K point sources at different distances away from the scintillator. The aim of this *numerical* experiment was to calculate the minimum alarm activities that trigger the RPM and compare them with the experimental ones.

Spectral response simulations were also conducted using the Monte Carlo code Gate with GEANT code of CERN [9], which has the ability to perform optical simulations. This was done to enhance light generation and transport phenomena along with gamma-ray interactions. The simulated geometry is the one shown in fig. 2. In optical simulations, gamma-rays interacting within the scintillator volume create optical photons which are tracked and measured by appropriate tallies in dielectric-metal boundaries. The surface between the light guide and the PMT was supposed to be such a boundary (*i. e.*, measuring surface). The optical photons' wavelength was equated to the main emission wavelength of the scintillator (418 nm). The optical photons' detection efficiency at the PMT surface (photocathode) for that wavelength was considered to be 25 % [10]. The output extracted from the optical simulations was a spectrum per position of the point source on the scintillator surface. Each spectrum plots the number of events that generated a certain number of optical photons *vs*. the total number of optical photons generated. Since the number of optical photons corresponds to the light intensity, which is proportional to the energy, the aforementioned spectra are analogous to energy spectra. In order to compare simulated and experimental spectra, the counts extracted from the simulations were normalized per starting photon. Monte Carlo simulations follow the history of numerous starting particles (in our case photons) undergoing interactions with matter. Afterwards, these counts are multiplied by the number of photons emitted per second from the 0.35 Ci ^{137}Cs source and now both spectra can be compared, representing the same quantity in cps units.

RESULTS AND DISCUSSION

Spatial response results

In fig. 3 the comparison between Monte Carlo simulations with the MCNP code and the count rate measurements by the RPM (after background subtraction), for a 0.35 μCi ^{137}Cs point source, positioned on the surface of the scintillator and at different distances from the PMT, is shown. The uncertainty of the measured results is within the dimensions of the points in fig. 3 and it was estimated by calculating the square root of the mean value of counts, assuming the distribution of counts is following the Poisson distribution [11]. The detector's output in cps seems to be constant as the source is moving away from the PMT, while in front of the scintillator (20 cm < x < 75 cm). For the source positioned at x <20 cm, the total counts are lower because the source is near the boundary surface of the scintillator and the light guide (which does not scintillate). A quite good qualitative and quantitative agreement between experimental measurements and Monte Carlo simulations is observed, showing that plastic scintillator response can be simulated adequately by the MCNP code, when the total energy window of the RPM (22-1595 keV) is used.

It can be seen that Monte Carlo simulation results follow the trend of the curve obtained with the experimental results. The simulation results are of the same order of magnitude compared with the experimental ones. Taking into account the rough geometry dimensions, the behaviour of optical photons and electronics, that are not simulated with Monte Carlo simulation, the simulated results are within 10 % of the experimental ones, which indicates a relative good agreement between them.

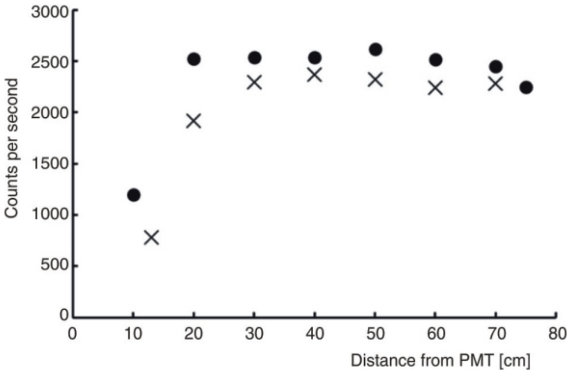

Figure 3. Comparison between count rate (cps), measured (x), and calculated (circles) by Monte Carlo simulations (MCNP) for a 0.35 Ci ^{137}Cs source positioned on the surface of the scintillator at different distances from the PMT

The next step was to measure and calculate the intrinsic efficiency of the scintillator of the RPM. Intrinsic efficiency is the ratio of all photons which cause a measurable impulse within the detector to all photon's incident to the detector. The measured intrinsic efficiency for 661.6 keV photons was 0.441 and the calculated one 0.456.

In fig. 4, the comparison between Monte Carlo simulations and the count rate measurements by the RPM (after background subtraction) for the 0.35 μCi ^{137}Cs point source, positioned in different distances away from the scintillator, is shown. Again, a quite good qualitative and quantitative agreement between experimental measurements and Monte Carlo simulations is observed. Monte Carlo simulations were also performed for ^{60}Co and ^{40}K point sources, at different distances (0-3 meters) away from the scintillator. These measurements were performed in order to take into account the detector's geometry that is quite large and in fact the inverse square law cannot be applied accurately.

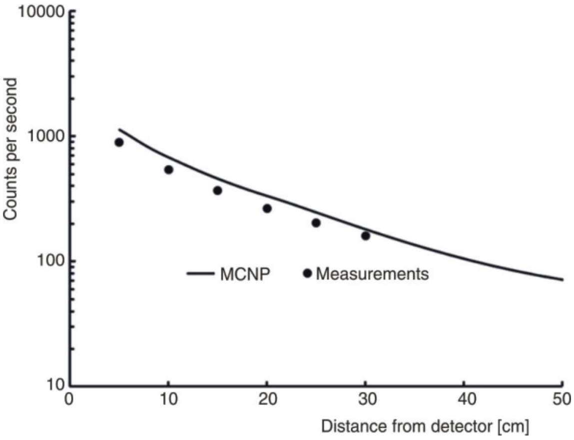

Figure 4. Comparison between count rate (cps), measured (points), and calculated (line) by MC simulations for a 0.35 Ci ^{137}Cs source positioned in at different distances from the scintillator of the RPM

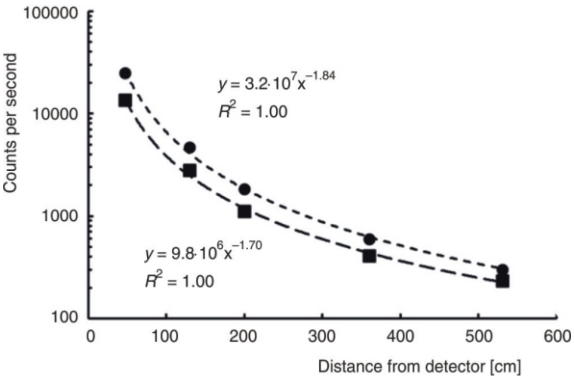

Figure 5. Response of the RPM for two energy windows: narrow window (22-144 keV) in squared points and total window (22-1595 keV) in circle points, as a function of the distance of a 42.5 Ci ^{152}Eu point source from the scintillator

The output of the RPM, as function of the distance from the scintillator, of a 42.5 μCi ^{152}Eu point source, for two energy windows of the RPM: narrow window (22-144 keV) and total window (22-1595 keV), is shown in fig. 5. As expected, using the narrow window (22-144 keV), the cps measured by the RPM are lower than those measured with the total window. Following the important role of the background in the calculation of the threshold, over which the alarm will be triggered in the RPM, eq. (1), it is important to define the signal/background ratio, as the ratio of the signal produced by the source and the signal produced by the background radiation level with no source present. In the *Evzoni* custom area, the output of the detector due to background radiation is 303 cps for the total window and 144 cps for the narrow window. The signal/background ratio, for the two energy windows (total and narrow), as function of the distance of the ^{152}Eu point source from the RPM can be seen in fig. 6. Signal/background ratio is higher when the narrow window is used than when the total window is used. This means that the background radiation contributes less to total counts when using the narrow window than using the wider one and the sensitivity of the instrument is better in the first case. This is another reason to use a narrow window than a total window. The first reason, as mentioned previously, is that the low energy window favours the detection of ^{235}U due to photon peak at 186 keV and its Compton edge is around 78 keV.

Results of minimum alarm activities (in static conditions)

The static tests consisted of positioning the point sources (^{152}Eu and ^{137}Cs) equidistantly between the two pillars of the RPM at the half of the scintillator height. The ^{152}Eu source 42.5 μCi (unshielded) was located in the mid-height to the scintillator and at the half distance

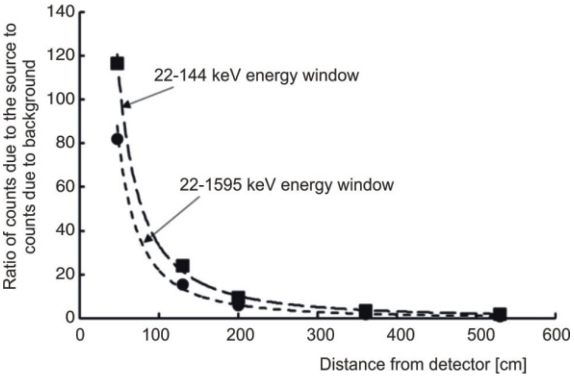

Figure 6. Signal/background ratio for the two energy windows (total and narrow window) as function of the distance of the ^{152}Eu point source from the scintillator

between the two pillars of the RPM (3 meters). The unshielded ^{137}Cs point source, of activity 0.35 μCi, was located up to 0.3 meters from the detector. The system is set to allow detections to be registered without the need to simulate the passing of a vehicle. In real situations, the alarm triggering of the RPM is produced during dynamic conditions (passage of a vehicle between the two pillars of the RPM) and not static conditions. However, in a previous work [12] it was shown that dynamic measurements can be approximated by corresponding static measurements for specific transit conditions (*e. g.*, low vehicle speed).

The measurement in the RPM due to the ^{152}Eu source (background subtracted) is 604 cps, more than 5 times higher than the background (background at the time of measurement was 116 cps). The energy window of the RPM is the default one (22-144 keV). The RPM with plastic detectors generally use a pre-set alarm threshold 4-6 standard deviations of the background [13]. With $c = 4$ in eq. (1), a minimum alarm activity of about 3 μCi (111 kBq) is deduced, considering linearity to the response of the scintillation detector.

Unfortunately, a high activity ^{137}Cs source, in order to perform measurements at 3 meters (half distance between the two pillars of the RPM), was unavailable. However, measurements with an unshielded ^{137}Cs point source, of activity 0.35 μCi up to 0.3 meters from the detector, were performed, fig. 4. The measurement in the RPM due to the source at 30 cm was 161 cps. In order to deduce the cps at a distance d = 3 m we use the $d^{-1.7}$ dependence, found experimentally for the ^{152}Eu source, fig. 5, and by Monte Carlo simulations with ^{137}Cs source. With such dependence, the estimated cps for a ^{137}Cs 0.35 μCi source at 3 meters is 3.2 cps. The count rate, measured by the RPM due to Background, was 144 cps. A minimum alarm activity of about 5.25 μCi (194 kBq) is estimated (for c = 4).

Theoretical calculations of the minimum activities of ^{137}Cs, ^{60}Co, and ^{40}K point sources, for alarm triggering of the RPM, were performed by Monte Carlo simulations. The total energy window (22-1595 keV) was adopted in the simulations compared to the default one (22-144 keV), as the plastic scintillator response was simulated adequately by the MCNP code when the total energy window of the RPM (22-1595 keV) is used, figs. 3 and 4. In a previous study [14], it was shown that MCNP code cannot simulate adequately the plastic scintillator response to gamma radiation, when narrow windows are used.

In tab. 1 the calculated (by MC simulations) absolute efficiency (cps of the detector per μCi) for ^{137}Cs, ^{60}Co, and ^{40}K point sources, located 3 meters away from the scintillator (half distance between the two pillars of the RPM), are presented. In order to calculate the minimum alarm activity, it was assumed that the cps, measured by the detector due to the source is four standard deviations of the cps of the background.

Table 1. Minimum activities for alarm triggering of the RPM as deduced by the Monte Carlo simulations

Point source	Absolute efficiency [cps/μCi]	Minimum activity [μCi]
^{137}Cs	11.9	5.9
^{60}Co	38.0	1.8
^{40}K	1.2	58.8

In the *Evzoni* area the counts per second due to background is 303 cps for the total energy window (22-1595 keV) of the scintillator. The minimum activity of the source for triggering the alarm corresponds to $4\sqrt{\ }$ cps, detected in the scintillator, due only to the source (background subtracted). Dividing the value of 70 cps by the tabulated values of the absolute efficiency of the detector (second column of tab. 1) we deduce the minimum activities for triggering the alarm, which are presented in 3rd column.

The calculated value, of 5.9 μCi for the ^{137}Cs source, is in good agreement with the value of 5.25 μCi deduced experimentally. In a study [15] in 19 RPM in Spain, it was found that the minimum ^{137}Cs activities for alarm triggering of the RPM were between 170-280 kBq (4.32 -7.56 μCi), which is in accordance with our values. It should be noted, that the minimum alarm activity of the RPM is not the minimum detectable activity by the RPM, which has a lower value [15].

Spectral response results

The spectra shown in fig. 7 were obtained with the ^{137}Cs source placed on the surface of the scintillator for different distances from the PMT. The broad peaks in fig. 7 do not correspond to the ^{137}Cs photopeak at 661.6 keV. In a detector, the gamma quantum with the energy, E, can be completely absorbed (photopeak), but a Compton effect can occur as well so that the gamma quantum escapes from the detector and only the energy of the electron is detected [10]. The energy of this electron lies between zero and the maximum value, which

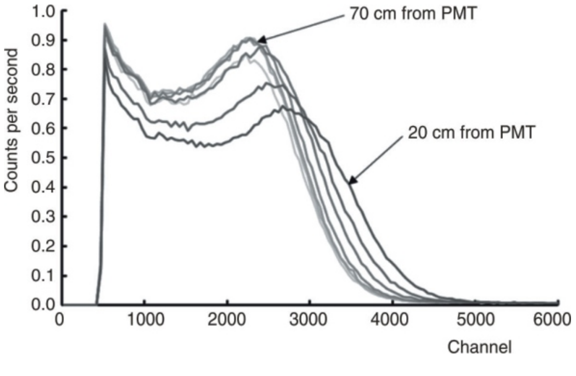

Figure 7. Comparison between spectra obtained with the ^{137}Cs source placed on the surface of the scintillator for different distances (20-70, and 75 cm) from the PMT

corresponds to 180° backscattering, leading to a continuum from zero up to the Compton edge (478 keV for gamma rays due ^{137}Cs). The small thickness and the low *Z* elements (C, H) of the scintillator, favour Compton scattering rather than photoelectric process (completely absorption of the incident photon energy). The broad peaks shown in experimental spectra, fig. 7 correspond to the Compton Edge. This is impressively shown in fig. 8(a) where the results of Monte Carlo simulations are shown for a ^{137}Cs source placed in on the surface of the scintillator and at different distances (20-70, and 75 cm) away from the PMT. The high broad peak in fig. 8(a) corresponds to the Compton edge. In the simulated spectra a small peak can also be observed, which corresponds to the ^{137}Cs photopeak at 661.6 keV. The fact that the small photopeak is not observed in the experimental spectra is due to the resolution of the plastic scintillator. As an example , by treating the simulated spectra at $x = 20$ cm with a Gaussian filter in order to be consistent with the scintillating detector's energy resolution (which is about 20 % at 1 MeV [10]) the small peak which corresponds to the ^{137}Cs photopeak at 661.6 keV is not visible anymore in the simulated spectra as shown in fig. 8(b).

In the measured spectra in fig. 7 there is an evident displacement of the Compton edge towards lower energies as the source is moving further away from the PMT. Furthermore, the counts in the lower part of the continuum are increasing for the same source movement. The total counts measured in any case (integrated surface under the spectra) are almost the same. On the contrary, the simulated spectra with the MCNP code in fig. 8(a), shows no Compton edge displacement. The spectra for the different distances from the PMT practically coincide. The displacement of the Compton Edge in the experimental spectra is caused by light attenuation and other light transport phenomena inside the scintillator, which the MCNP code cannot model. The mechanism that explains the Compton edge displacement is the following: in scintillating detectors, light intensity corresponds to energy. Therefore, an attenuated light intensity will eventually be recorded as a lower energy signal. Hence, the further away from the PMT, the less the recorded energy will be for a particle of a given energy. In parallel with the MCNP code, optical simulations were conducted using the Monte Carlo code Gate with GEANT code of CERN which has the ability to perform optical simulations. This was done to enhance light generation and transport phenomena along with gamma-ray interactions. The spectra obtained from Gate simulations, fig. 9, shows qualitative similarities to the measured ones, fig. 7, showing a clear displacement of the Compton edge for the ^{137}Cs. In addition, the total cps is almost the same for the two positions of the ^{137}Cs source. The cps values measured and calculated by MC simulations with MCNP and Gate for two positions ($x = 30$ cm and $x = 70$ cm) of the ^{137}Cs from the PMT are compared in tab. 2. The total cps (corresponding to the full energy window of the RPM) measured or calculated by MC simulations (MCNP, GATE) are almost the same for the two source distances from the PMT. In addition, a quite good agreement between measurements and MC simulations is found.

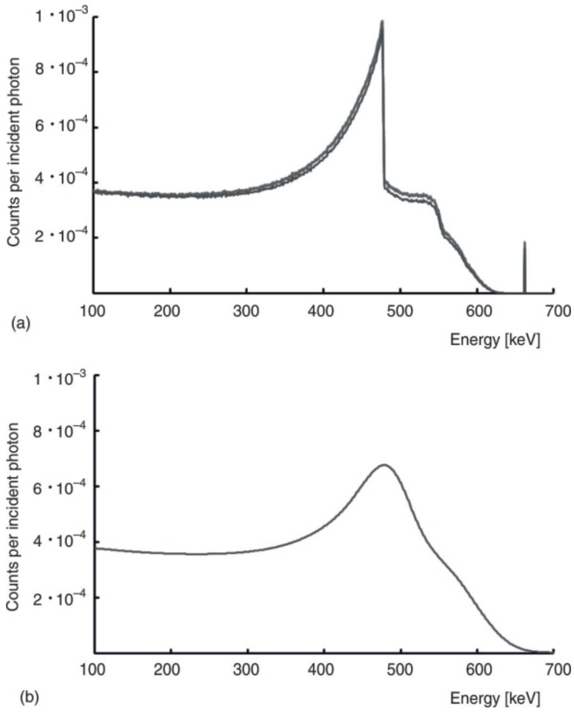

Figure 8. (a) Monte Carlo (MCNP code) simulated spectra for ^{137}Cs source for 1 keV energy bins and for different distances (20-70, and 75 cm) away from the PMT; the spectra for the different distances coincide, (b) Monte Carlo (MCNP code) simulated spectra for a distance of 20 cm away from the PMT with Gaussian broadening

CONCLUSIONS

During the INTERREG project with the acronym STRASS, a collaboration project between Greece and North Macedonia, among other issues, the spatial and spectral response of RPM installed in the cross-border area of both countries was examined.

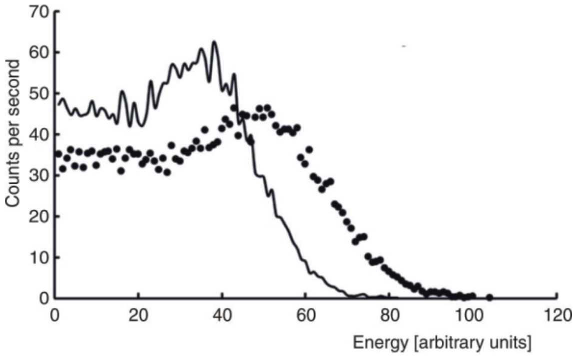

Figure 9. Gate simulated spectra for the ^{137}Cs source on the surface of the scintillator for two distances from the PMT; (–) $x = 70$ cm, ( ) $x = 30$ cm

Table 2. Measured and calculated by MC simulations of RPM count rate for two positions of the 0.35 Ci ^{137}Cs source from the PMT

Distance from PMT [cm]	Experimental [cps]	MCNP [cps]	GATE [cps]
30	2295	2534	2653
70	2279	2448	2620

Although these types of plastic detectors are not used for spectrometry, spectra were obtained from the RPM using ^{137}Cs source in order to investigate their response. Spectral results obtained with a ^{137}Cs source placed on the surface of scintillator at different distances from the PMT show no photopeak (661 keV) due to total absorption of the energy of the gamma-ray. An energy shift of the Compton edge is shown in the spectra as the source is moving away from the PMT. This is due to light transfer mechanisms within the scintillator volume and therefore it is only observed in optical simulations (GATE) and not in gamma-ray particle simulations (MCNP). However, plastic scintillator response can be simulated adequately by the MCNP Monte Carlo code.

The Intrinsic efficiency of the scintillator of the RPM was measured using the aforementioned ^{137}Cs point source and compared to the calculated one. A good agreement between measured (0.441) and calculated (0.456) values was observed.

The RPM installed in the cross border area are using two energy windows: narrow energy window (22-144 keV) and a wider energy window (22-1595 keV). Their response was studied as a function of the distance from the RPM of a 42.5 Ci ^{152}Eu point source. It was shown that the signal/background ratio is higher when the narrow window is used compared to the wider window.

Minimum alarm activities of the RPM were estimated experimentally, for different radioactive point sources (^{137}Cs, ^{60}Co, ^{40}K). The calculated value by Monte Carlo simulations (5.9 μCi) for the ^{137}Cs source is in good agreement with the value of 5.25 Ci deduced experimentally. Therefore, Monte Carlo simulations represent a useful tool for estimating Minimum detectable activities of the instruments, giving accurate results without using expensive radioactive sources.

Knowing the limits of RPM, develops better practices in the cross-border checks, adjusting the RPM parameters in such a way to register true alarms and not false or innocent naturally occurring (NORM) ones.

ACKNOWLEDGMENT

This work was performed in the framework of STRASS project of the INTERREG IPA CBC Program Greece – Republic of North Macedonia 2014-2020 and is co-funded by the European Union and by National Funds of the participating countries.

AUTHORS' CONTRIBUTIONS

Measurements and simulations were performed by all the authors. The manuscript was written by A. Clouvas and S. Xanthos.

REFERENCES

[1] ***, International Atomic Energy Agency, Detection of Radioactive Materials at Borders, IAEA-TECDOC -1312, IAEA, Vienna 2002

[2] ***, International Atomic Energy Agency, Incidents of Nuclear and Other Radioactive Material Out of Regulatory Control, 2015, Available at: https://www.iaea.org/sites/default/files/19/04/itdb-factsheet-2019.pdf

[3] Sokolov, A., *et al*., The Development of Waste Assay Monitors Based on the HPGe Detectors, *Nucl Technol Radiat Prot., 33* (2018), 4, pp. 411-416

[4] ***, United States Customs and Border Protections Radiation Portal Monitors at Seaports, U.S. Department of Homeland Security, 2013, available at: https://www.oig.dhs.gov/assets/Mgmt/2013/OIG_13-26_Jan13.pdf

[5] Ely, J., *et al*., The Use of Energy Windowing to Discriminate SNM from NORM in Radiation Portal Monitors, *Nucl. Instr. and Meth. Phys. Res. Sect. A, 560* (2006), 2, pp. 373-387

[6] Presti, C., *et al*., Baseline Suppression of Vehicle Portal Monitor Gamma Count Profiles: A Characterization Study, *Nucl. Instr. and Meth. Phys. Res. Sect.A, 562* (2006), 1, pp. 281-297

[7] ***, Canberra Industries, Genie 2000 Operations Manual, Canberra Industries 2001

[8] Briesmeister, F., MCNP-A General Monte Carlo N-particle Transport Code, Version 4C. Los Alamos National Laboratory, Los Alamos 2000, N. Mex, USA, (LA-13709-M)

[9] ***, GEANT, Detector Description and Simulation Tool. Geneva. CERN. Program Library Long Write-up W5013, 1993

[10] Knoll, F., Radiation Detection and Measurement, (3rd edition), Wiley, New York, USA, 1999

[11] Gordon, G., *et al*., *Practical Gamma-Ray Spectrometry*, Wiley, New York, USA, 1995

[12] Takoudis, G., *et al*., Determining Minimum Alarm Activities of Orphan Sources in Scrap Loads; Monte Carlo Simulations, Validated with Measurements, *Nuclear Instruments and Methods in Physics Research,614* (2010), 1, pp. 57-67

[13] Apikyan, S., *et al*., Nuclear Terrorism and National Preparedness, *Proceedings*, NATO Advanced Research Workshop on Preparedness for Nuclear and Radiological Threats, Los Angeles, Cal., USA, 2015

[14] Takoudis, G., *et al*., Spatial and Spectral Gamma-Ray Response of Plastic Scintillators Used in Portal Radiation Detectors; Comparison of Measurements and Simulations, *Nuclear Instruments and Methods in Physics Research, 599* (2009), 1, pp. 74-81

[15] Cristina, C., Processes of Verification and Calibration of Portal Monitors for the Detection of Radioactive Sources in Metal Scrap, IRPA 12, On-line first, https://inis.iaea.org/search/ search.aspx?orig_q=RN:40108769.

Received on July 13, 2020
Accepted on September 17, 2020

Александрос КЛОУВАС, Фокион ЛЕОНТАРИС, Стелиос КСАНТОС

ОДЗИВ ПОРТАЛ МОНИТОРА ЗРАЧЕЊА НА ГАМА ЗРАЧЕЊЕ И СПОСОБНОСТ ДЕТЕКЦИЈЕ ЗАГУБЉЕНИХ ИЗВОРА РАДИОАКТИВНОСТИ – ДОПРИНОС STRASS ПРОЈЕКТА

Портал монитори зрачења обично се користе за откривање и пресретање неовлашћеног преноса нуклеарних и других радиоактивних материјала на границама државе. Укупно је дванаест портал монитора са двоструким стубовима постављено на грчко-северномакедонској граници, од којих сваки садржи два полистиренска сцинтилациона детектора по стубу. Испитивање просторног и спектралног одзива сцинтилационих детектора на гама зрачење извршено је коришћењем различитих радиоактивних извора и упоређивањем резултата мерења са Монте Карло симулацијама. Уочено је добро слагање експериментално изведених минималних активности различитих тачкастих извора, потребних за активирање аларма портал монитора зрачења, са израчунатим Монте Карло вредностима. Спектрални резултати показују да нема фото пикова у спектрима због ниске резолуције ових детектора. Широки пикови уочени у спектрима одговарају Комптоновој граници. Измерени спектри са извором ^{137}Cs постављеним директно на сцинтилациони детектор, на неколико положаја од фотомултипликаторске цеви, показују енергетски помак Комптонове границе ка нижим енергијама, док се извор удаљава од фотомултипликаторске цеви. До енергетског помака долази због механизама преноса светлости унутар запремине сцинтилатора, те се помак запажа само у оптичким симулацијама, а не и у симулацијама честица гама зрака.

Кључне речи: портал монитор зрачења, гама зрачење, загубљен радиоактивни извор, Монте Карло симулација