# COMPARISON OF THE RESPONSE OF DIFFERENT VOLTAGE DIVIDERS TO LOW-LEVEL MEASUREMENT USING A LARGE PLASTIC SCINTILLATOR INTENDED FOR RADIATION PORTAL MONITORS

by

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Scientific paper
https://doi.org/10.2298/NTRP2103249F

**The work deals with the comparison of voltage dividers with different wiring of resistors and capacitors. The voltage divider recommended by the manufacturer of the used photomultiplier (ET Enterprises, GB) was used as a reference. The aim was to assess the influence of different voltage dividers together with the large volume scintillation detector on detection parameters such as the efficiency of the measurement and dose rate linearity using $^{241}$Am, $^{137}$Cs, and $^{60}$Co gamma sources. The experiments showed relatively great differences between 15_10(_C) voltage divider (R1 and R2-R11, 15 M and 10 M) and the rest. Furthermore, it was confirmed that the voltage divider recommended by the manufacturer of the used photomultiplier showed the best results, but some of the measured dividers exhibited similar results and therefore can be used in radiation portal monitors as well.**

*Key word:* *voltage divider, radiation portal monitor, gamma-radiation, organic-based polystyrene scintillator*

## INTRODUCTION

Safety and security throughout the world have been constantly increasing, especially since the terrorist attacks on the 11th of September 2001 [1-4]. Radiation detectors have become a common part of the law enforcement authority, firefighters, rescuers, and other governmental and non-governmental agencies' work. Because of automation and fast screening methods of radiation detection, the radiation portal monitors (RPM), both for pedestrians and large vehicles (including ships and trains) have been employed [5-7]. Nowadays, two concepts are usually used; the first concept is based on the advanced spectroscopic portal (ASP) program, where high purity germanium portal monitors were evolved. The HPGe, having significantly better energy resolution than NaI(Tl), allows rather a precise measurement of the isotopes contributing to gamma-ray spectra [8, 9]. However, due to very high costs and major constraints such as cryo-cooling requirements, the use of these portals is very limited to special needs. Instead of HPGe detectors in portal monitors for radiation spectrometry, detectors based on more modern scintillation crystals as $LaB_{r3}$, $CrBr_3$, $SrI_2$ [10] could already be used. Due to significantly better energy resolution (3-4 % for $^{137}$Cs) than the traditional NaI (Tl) crystals, these crystals are already beginning to replace semiconductor detectors (HPGe, CdZnTe, SiC) in some spectrometric applications [11, 12]. However, their use in portal monitors is also constrained until now by their high cost.

The second and the most widespread concept of RPMs is based on organic scintillators, especially plastic scintillators. These detectors, contrary to semiconductor detectors, provide limited information on the energy of detected photons, thus are unable to distinguish gamma-rays originating from nuclear sources and from gamma-rays originating from NORM materials causing false alarms. This disadvantage was recently suppressed using advanced discrimination algorithms [13-15]. Due to the ability to detect fissile materials, the portal monitors are sometimes equipped with neutron detectors based on the He-3 tube [16, 17] or B-10 (Li-6) loaded ZnS: Ag detectors [18, 19].

As can be seen, there has been great effort to improve the detection media, PMT, MCA, and detection algorithms, but little has been improved on voltage dividers. Users usually work with PMT-dividers sup-

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**Table 1. Overview of the compared voltage dividers**

| R1 [MΩ] | R2…R7 [MΩ] | R8 [MΩ] | R9 [MΩ] | R10 [MΩ] | R11 [MΩ] | C1 [nF] | C2 [nF] | C3 [nF] | C4 [nF] | Label |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.66 | | | 0.33 | | | – | – | | – | ETE_STD[1] |
| 0.66 | 0.33 | 0.66 | 1 | 1.2 | 1 | – | – | – | – | ETE_HPL[2] |
| 0.82 | | | 0.56 | | | – | – | – | – | 0.82_0.56 |
| 1 | | | 0.56 | | | – | ¬ 10 | | 2.2 | 1_0.56 |
| 1.5 | | | 1 | | | – | – | – | – | 1.5_1 |
| 2.2 | | | 1.5 | | | 22 | 22 | 22 | 1 | 2.2_1.5 |
| 15 | | | 10 | | | – | – | – | – | 15_10 |
| 15 | | | 10 | | | – | 10 | | 2.2 | 15_10_C |

[1] represented configuration recommended by the manufacturer of the used PMT
[2] represented high-pulsed linearity tapered type of voltage divider

plied by the manufacturers of the detectors without the assurance of the proper PMT-divider matching, which greatly influences the quality of the read-out signal. The literature relating to the problematics of voltage dividers and their combination with PMT is very few [20, 21]. The choice of voltage divider depends on the use of the detector (continuous mode, pulse mode) and the measurement requirements (gain, linearity, timing, stability). The recommended arrangement of voltage dividers is usually determined by their manufacturer.

The purpose of this paper was to evaluate the influence of different voltage dividers in connection with the large volume polystyrene scintillation detector on detection parameters such as the efficiency of the measurement and dose rate linearity.

## MATERIAL AND METHOD

### Device and equipment

The 25 L plastic detector with a dimension of 100 cm × 50 cm × 5 cm (Nuvia, CZ) was chosen. The composition of the detector was as follows – polystyrene matrix with p-terphenyl (PTP) as a primary fluor and 1,4-bis(5-phenyl oxazole-2-yl) benzene (POPOP) as a wavelength shifter. The 2" PMT with circular photocathode type 9266KB50 (ET Enterprises, GB) was used. The SCA-T analyzer (Nuvia, CZ) was used as read-out electronics using GamWin (Nuvia, CZ) spectrometric software for spectra evaluation. The time of the measurement was set to 100 seconds and each measurement was three times repeated. Since the magnitude of the high voltage of portal monitors is set automatically using the program *HVSet*, the magnitude of the HV was set the same way for each voltage divider before each measurement. The logic of this program is based on the creation of two ROI (region of interests), one in the low-energy and the other in the high-energy part of the spectrum. Their ratio gives a certain value, which changes with the change of the high voltage. The ideal spectrum gives value, which was mathematically computed and statistically evaluated. The *HVSet* program increases the high voltage and compares the ratio of the selected ROI with the ideal value until these two values are equal. This procedure ensures the proper spectrum position, *i. e.*, that the Compton edge always corresponds to the same channel. This should maintain the same gain for all voltage dividers used.

The $^{241}$Am, $^{137}$Cs, and $^{60}$Co radionuclide sources type EG3 (Eurostandard, CZ) of activities of $A_{Am\text{-}241}$ = =.539.6 kBq, $A_{Cs\text{-}137}$ = 306.5 kBq and $A_{Co\text{-}60}$ = 235.7 kBq were used to evaluate the detection characteristics.

The motivation of this work was to investigate the effect of different resistors and capacitors on detector efficiency, the shape of the spectrum, linearity, and other parameters overall of eight different voltage dividers listed in the tab. 1, where the resistance and capacitor values are given as well. The positions of different resistors and capacitors are shown in fig. 1.

The voltage dividers were selected to cover the range of resistances from the smallest to the largest, taking into account the manufacturer's recommendation to maintain the ratio between the first and second dynodes and the high voltage source used in the SCA.

### Measurement set-up

The detector center was marked and then was fastened to the stand in height of 1 m above the ground. The measurements were carried out according to the same procedure for all radionuclides; the selected radionuclide was placed at a certain distance varying from 1 m up to 5 m directly opposite to the marked center of the detector. Afterward, the measurement was three times repeated at the

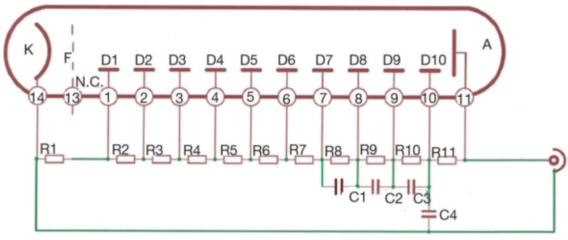

**Figure 1. Schematic diagram of a voltage divider circuit**

**Table 2. Power functions and coefficients of determination for selected voltage dividers obtained from measured data points at different distances for selected radionuclides**

| Voltage divider | $^{241}$Am | | $^{137}$Cs | | $^{60}$Co | |
|---|---|---|---|---|---|---|
| | Power function y | Coefficient of determination R2 | Power function y | Coefficient of determination R2 | Power function y | Coefficient of determination R2 |
| ETE_STD | $1361.9x^{-1.752}$ | 0.9984 | $3796.2x^{-1.804}$ | 0.996 | $5074.7x^{-1.668}$ | 0.9979 |
| ETE_HPL | No fit | | $3236.4x^{-1.351}$ | 0.9673 | $4670.5x^{-1.535}$ | 0.9996 |
| 0.82_0.56 | $1530x^{-2.171}$ | 0.9865 | $3706.8x^{-1.71}$ | 0.9932 | $4999.8x^{-1.735}$ | 0.9968 |
| 1_0.56 | $1665.8x^{-2.306}$ | 0.9538 | $3678.9x^{-1.788}$ | 0.9954 | $4758.7x^{-1.716}$ | 0.9957 |
| 1.5_1 | $1757.1x^{-2.189}$ | 0.8797 | $3695.7x^{-1.736}$ | 0.9961 | $4941.1x^{-1.779}$ | 0.9945 |
| 2.2_1.5 | $1515.2x^{-2.059}$ | 0.9419 | $3698.3x^{-1.767}$ | 0.995 | $4671.6x^{-1.605}$ | 0.9954 |
| 15_10 | No fit | | $3360.4x^{-1.596}$ | 0.9871 | $5494.2x^{-2.191}$ | 0.9663 |
| 15_10_C | $1530x^{-2.171}$ | 0.9865 | $4801x^{-2.463}$ | 0.9237 | $4987x^{-1.803}$ | 0.9924 |

same distance to a preset time (live time) of 100 seconds. The background was measured in the same way. The net spectrum was calculated by subtracting the average background from the average spectrum at each distance. The procedure was repeated for all radionuclides and voltage dividers. The count rate (measured in counts per second – cps) at the different positions was calculated as the net integral of pulses in each channel (1-1024) divided by live time (100 seconds).

The detection efficiency was calculated by

$$\eta_{\text{tot}} \quad \frac{N}{At} \quad 100 \qquad (1)$$

where $A$ – source activity calculated to the date of measurement [Bq], $N$ – net integral of pulses in each channel of spectrum over time $t$, and $\eta_{\text{tot}}$ absolute efficiency [%].

## RESULTS AND DISCUSSION

### Efficiency measurement

In the case of the $^{241}$Am- measurement, the count rate against distance was plotted and is shown in fig. 2. The best fit was observed for the standard voltage divider circuit suggested by ET Enterprises (ET_STD) followed by the 15_10_C voltage divider. Contrary to that, the worst fit was observed for the voltage divider labeled as 15_10, together with the lowest sensitivity, tab. 2.

As for $^{137}$Cs, the worst fit exhibited voltage divider labeled 15_10_C followed by ET HPL and 15_10. All other voltage dividers showed excellent quadratic fit from which the ET_STD exhibited the best result, especially, when a low count rate was measured, fig. 3.

In the case of high-energy photons, here represented by photons emitted from $^{60}$Co source, the best quadratic fit of count rate at different distances was observed using ET HPL voltage divider reaching almost the absolute value. All other voltage dividers showed excellent quadratic fit except for voltage diver labeled 15_10, which is seen in fig. 4.

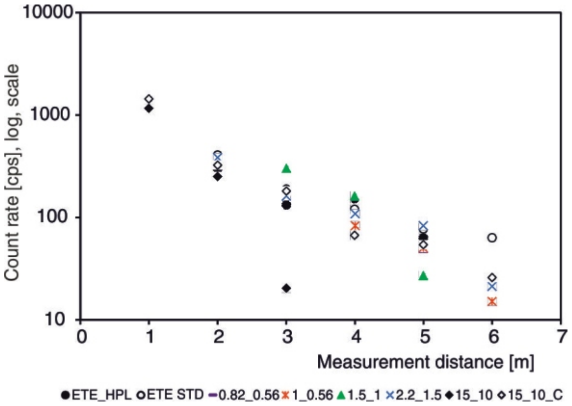

**Figure 2. The dependence of the measured count rate on $^{241}$Am source distance**

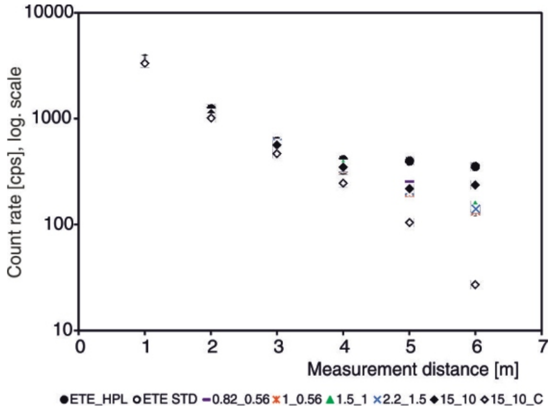

**Figure 3. The dependence of the measured count rate on $^{137}$Cs source distance**

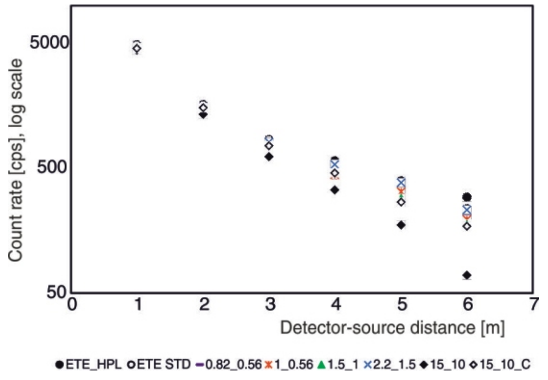

**Figure 4. The dependence of the measured count rate on $^{60}$Co source distance**

**Table 3. The detection efficiencies of studied voltage dividers at different source-detector distances. To each detector-source distance, the dose rate (*D*) was calculated**

| Detection efficiency of $^{241}$Am [$10^{-3}$ %] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Distance [m] | ETE_STD | ETE_HPL | 0.82_0.56 | 1_0.56 | 1.5_1 | 2.2_1.5 | 15_10 | 15_10_CD | $\dot{D}$ [nSvh$^{-1}$] |
| 1 | 258 | 232 | 245 | 240 | 244 | 246 | 215 | 267 | 2.1 |
| 2 | 76 | 55 | 68 | 70 | 66 | 71 | 47 | 60 | 0.52 |
| 3 | 35 | 25 | 30 | 33 | 56 | 30 | 4 | 34 | 0.23 |
| 4 | 22 | 28 | 13 | 15 | 30 | 20 | NA | 12 | 0.13 |
| 5 | 14 | 12 | 9 | 9 | 5 | 15 | NA | 10 | 0.08 |
| 6 | 12 | NA | 3 | 3 | 4 | 4 | NA | 5 | 0.05 |
| Detection efficiency of $^{137}$Cs [%] | | | | | | | | | |
| 1 | 1.162 | 1.196 | 1.153 | 1.129 | 1.149 | 1.123 | 1.136 | 1.094 | 23 |
| 2 | 0.367 | 0.403 | 0.374 | 0.352 | 0.368 | 0.365 | 0.365 | 0.332 | 5.8 |
| 3 | 0.183 | 0.198 | 0.191 | 0.185 | 0.188 | 0.192 | 0.184 | 0.153 | 2.6 |
| 4 | 0.107 | 0.134 | 0.123 | 0.11 | 0.122 | 0.112 | 0.114 | 0.081 | 1.4 |
| 5 | 0.07 | 0.13 | 0.084 | 0.066 | 0.071 | 0.068 | 0.071 | 0.034 | 0.92 |
| 6 | 0.043 | 0.115 | 0.048 | 0.044 | 0.05 | 0.046 | 0.077 | 0.009 | 0.64 |
| Detection efficiency of $^{60}$Co [%] | | | | | | | | | |
| 1 | 2.07 | 1.97 | 1.99 | 1.92 | 1.96 | 1.93 | 1.87 | 1.92 | 72.2 |
| 2 | 0.69 | 0.69 | 0.67 | 0.64 | 0.62 | 0.65 | 0.57 | 0.64 | 17.9 |
| 3 | 0.36 | 0.36 | 0.34 | 0.32 | 0.32 | 0.34 | 0.26 | 0.32 | 7.9 |
| 4 | 0.23 | 0.24 | 0.21 | 0.19 | 0.19 | 0.23 | 0.14 | 0.19 | 4.5 |
| 5 | 0.15 | 0.17 | 0.12 | 0.14 | 0.12 | 0.16 | 0.07 | 0.11 | 2.9 |
| 6 | 0.1 | 0.13 | 0.09 | 0.08 | 0.08 | 0.1 | 0.03 | 0.07 | 1.9 |

Since the count rate, as well as dose rate, should decrease with the square of the distance, all data points were fitted by power function to obtain the model function and the coefficient of determination to evaluate how well-observed outcomes were replicated by the model, tab. 2.

The best fit was observed for high-energy photons, where almost all voltage dividers, except for 15_10, follow power function fit with a very good coefficient of determination. A similar situation can be seen for medium energies represented by $^{137}$Cs, where not only the 15_10 voltage divider but also ETE_HPL and 15_10_C did not precisely follow power fit. The worst situation can be seen at low energies (represented by Am-241), where only three voltage dividers reasonably followed the power function. Table 3 represents a comparison of the detector efficiencies with individual voltage dividers; the calculation was performed as a simple ratio of the measured pulses to the used radionuclides activities related to the measurement date. As can be seen, there was a certain pattern of decreasing efficiency in soft dividers. Overall, the worst detection efficiencies were observed for the 15_10 voltage divider, especially when a low count rate was measured.

## Signal stability

One of the important factors of RPM is the ability to provide a steady signal in the case of background measurement. The steadiest the signal is, the better dis-

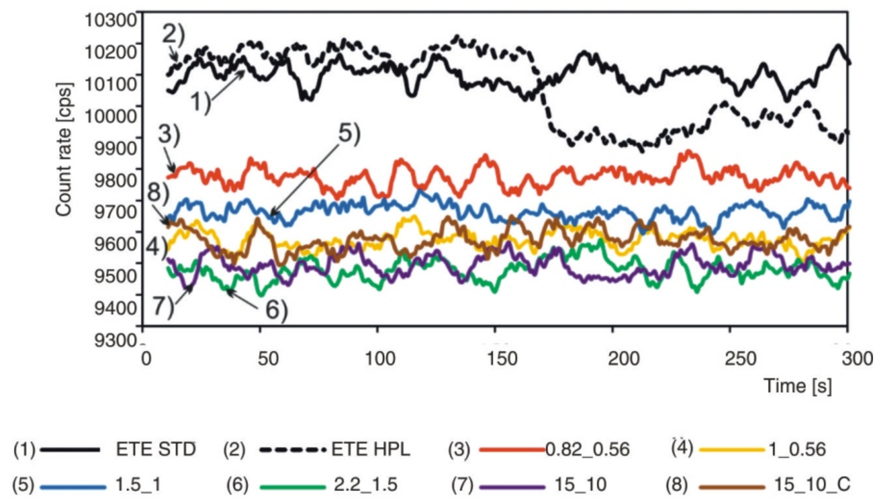

**Figure 5. Signal stability within five minutes of background measurement**

tinguishing between background and *true* signal is possible. As can be seen in fig. 5, the variance in signals provided from all voltage dividers within five minutes was 97.2 4 cps. The only exception was measurement with the ETE HPL voltage divider, where a high decrease in count rate was observed resulting in the signal variance of 153 cps.

As shown above (figs. 2-4), the worst performance was observed at dividers labeled 15_10(_C). The possible explanation of the behavior of 15_10 (_C) voltage dividers based on [22] includes a poor signal-to-noise ratio (SNR) for low energies and at the same time saturation at high energies. The possible cause of changing SNR at low energies, here represented by 59.5 keV of $^{24}$Am, is probably related to the anode load resistor. For positive high voltage applied to the anode, the load resistance is the parallel combination of R40 (bias resistor) and R41 (preamplifier input resistor) shown in fig. 6. The stability of the output pulse amplitude depending on the incoming count rate is also determined by the ratio of the total current of the divider concerning the anode current of the PMT. If the total resistance of the divider is large, the current is small and the output voltage is weak. For this reason, the divider with the lowest overall resistance also had the best properties.

The SCA used for measurement has the magnitude of the bias resistor, $R_a$, equal to 100 k and input resistance, $R_{in}$, equal to 4.7 k . Using these values, the load resistance becomes 4489 . This low value of load resistance in combination with the high resistance of the voltage divider increases the frequency bandwidth, which in turn decreases SNR. This can further lead to low detection efficiency for very low count rates at low energies.

The problem with saturation at high energies can be attributed to the high pulse current in PMT caused by the high incident photon energy, which in this case is represented by photons ($E_1$ = 1173.23 keV and $E_2$ = = 1332.51) of $^{60}$Co. With a high pulse current, electron density near the last dynode also increases and causes space charge effects, which leads to output saturation and a decrease of output count rate.

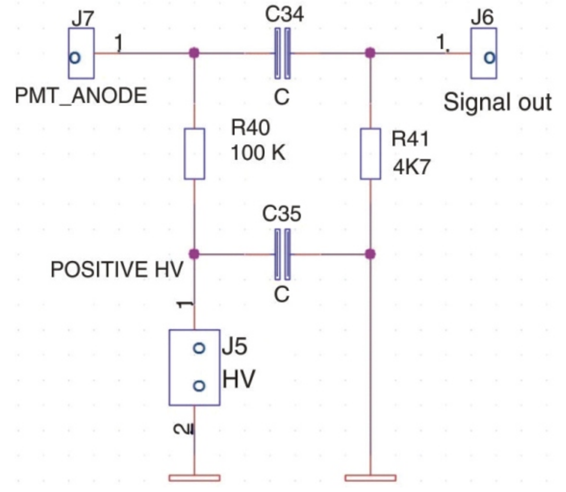

**Figure 6. Detail drawing of end part of 15_10 divider, where $R_{load} = R_a \parallel R_L$ = R40 || R41**

## CONCLUSION

The paper is aimed at evaluating the influence of the different voltage dividers on basic parameters such as the linearity of measurement, detection efficiency, and signal stability. The ETE STD voltage divider, which is recommended by the PMTs manufacturer, showed the best results obtained throughout all measurements. All other voltage dividers, besides 15_10 and 15_10_C voltage dividers, exhibited slightly worse results, which, in particulars at real measurements, can be neglected. The voltage divider labeled as 0.82_0.56 showed the second-best results, followed by 1_0.56 and 2.2_1.5. The worst results obtained from the measurement exhibited 15_10_C, but more importantly 15_10 voltage dividers, but even in their cases, the differences were not found to be critical for their use in industry or safeguard applications. Furthermore, other conditions are affecting the output signal, such as a high voltage divider circuit connection. In the configuration used for measurement, the high voltage divider is connected by a coaxial cable, which also serves as a high voltage power supply connection. In this type of connection, especially in combination with passive high voltage dividers, the parasitic capacitance of the cable should also be considered. The behavior of this (large) passive resistor-capacitor network also depends on the input characteristics of a connected measurement device. In this case, every setup should be carefully inspected regarding SNR, resulting in output pulse shape and dynamics of the resulting circuit.

## AUTHORS' CONTRIBUTIONS

The idea for this study was put forward by L. Fiserova. The measurements, theoretical calculations, and data evaluation were carried out by L. Fiserova and J. Janda. Explanation of the behavior of 15_10_C voltage dividers was performed by P. Skotak.

## ACKNOWLEDGMENT

This research work has been carried out within the ADAR project (Accelerator Driven Advanced Reactor). The authors gratefully acknowledge the financial support from the Ministry of Education, Youth, and Sports of the Czech Republic under the INTER-ACTION research program (project No. LTAUSA 18198).

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Received on June 24, 2021
Accepted on November 8, 2021

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## ПОРЕЂЕЊЕ ОДЗИВА РАЗЛИЧИТИХ РАЗДЕЛНИКА НАПОНА НА МЕРЕЊЕ НИСКОГ НИВОА КОРИШЋЕЊЕМ ВЕЛИКОГ ПЛАСТИЧНОГ СЦИНТИЛАТОРА НАМЕЊЕНОГ ЗА ПОРТАЛ МОНИТОРЕ ЗРАЧЕЊА

Рад се бави поређењем разделника напона са различитим ожичењем отпорника и кондензатора. Као референца употребљен је разделник напона који је препоручио произвођач коришћеног фотомултипликатора (ET Enterprises, GB). Циљ је био да се процени утицај различитих разделника напона заједно са сцинтилационим детектором велике запремине на параметре детекције, као што су ефикасност мерења и линеарност јачине дозе, коришћењем гама извора $^{241}$Am, $^{137}$Cs, и $^{60}$Co. Експерименти су показали релативно велике разлике између 15_10(_C) разделника напона (R1 и R2-R11; 15 и 10 M ) и осталих. Надаље, потврђено је да је разделник напона који је препоручио произвођач коришћеног фотомултипликатора показао најбоље резултате, али су неки од измерених разделника имали сличне резултате и стога се могу користити и у портал мониторима зрачења.

*Кључне речи: разделник напона, портал монитор зрачења, гама зрачење, органски полистиренски сцинтилатор*