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Technical note

Optimization of the Timepix chip to measurement of radon, thoron and their progenies

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HIGHLIGHTS

- Energy calibration of the Timepix chip for alpha particle measurement.
- Linear dependency between cluster volume and energy.
- Radon, thoron and their progenies analysis.

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ABSTRACT

Radon and thoron as well as their short-lived progenies are decay products of the radium and thorium series decays. They are the most important radionuclide elements with respect to public exposure. To utilize the semiconductor pixel radiation Timepix chip for the measurement of active and real-time alpha particles from radon, thoron and their progenies, it is necessary to check the registration and visualization of the chip.

An energy check for radon, thoron and their progenies, as well as for ^{241}Am and^{210}Po sources, was performed using the radon and thoron chambers at NIRS (National Institute of Radiological Sciences). The check found an energy resolution of 200 keV with a 14% efficiency as well as a linear dependency between the channel number (cluster volume) and the energy. The coefficient of determination r^2 of 0.99 for the range of 5 to 9 MeV was calculated. In addition, an offset for specific Timepix configurations between pre-calibration for low energy from 6 to 60 keV, and the actual calibration for alpha particles with energies from 4000 to 9000 keV, was detected.

1. Introduction

Inhalation of radon (Rn) and its short-lived decay products, as well as inhalation of products of the thoron (Tn) series, account for about half of the world-average effective dose from natural radiation sources (UNSCEAR, 2008). Many types of passive monitors and devices for radon and thoron measurement have been developed. The most common monitors for large-scale and long-term radon measurements are passive type monitors (Janik et al., 2014) utilizing etched-track solid state nuclear track detectors (SSNTDs) commercially known as CR-39 or LR 115 (Dwivedi et al., 2001; Mishra and Mayya, 2008; Zhuo et al., 2002). Recently, new monitor types based on radon absorption in solid polymers processes have been developed (Pressyanov et al., 2013; Tommasino, 2010; Tommasino et al., 2009). However, the results of measurements made using passive type monitors are obtained only after chemical or electro-chemical treatment of the detection materials and counting by manual or automatic systems. Some progress is being made using electronic passive monitors with on-line displayed results, e.g. the RadonScout and ThoronScout, the Corentium Digital Electronic Radon Gas Monitor, an active radon exposure meter developed by the Helmholtz Center Munich (Irlinger et al., 2014) as well as a new type of radon monitor based on the Timepix device (Caresana et al., 2014).

In this study, the Timepix device (Llopart et al., 2007) developed at CERN was calibrated at the NIRS, checked for application suitability and utilized for visualization of alpha particles. Moreover, the performance of the Timepix was also confirmed through experiments in the NIRS radon and thoron chambers.

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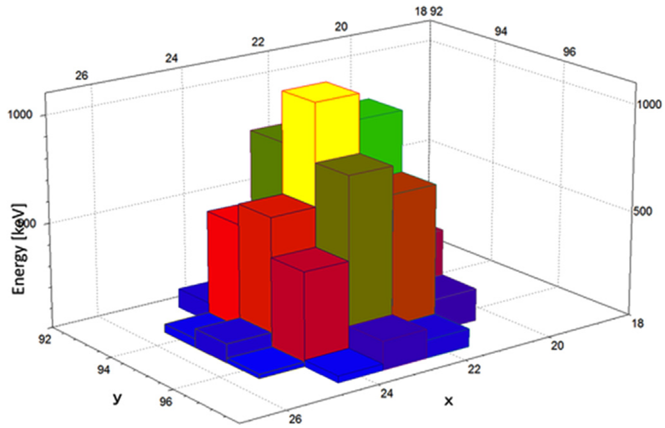

Fig. 1. Cluster of pixels caused by a single alpha particle from ^{241}Am.

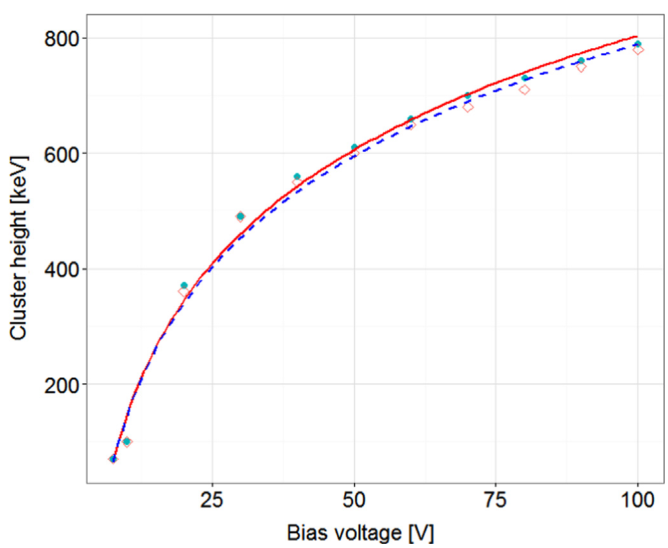

Fig. 2. Log-normal fitting (solid line - ^{241}Am, dashed line – ^{210}Po) for the relationship between cluster height and bias voltage for alpha particles from ^{241}Am (A) and ^{210}Po (P).

2. Methodology

Originally the Timepix device was designed for position-sensitive single X-ray photon detection. The hybrid silicon pixel device Timepix consists of a pixelated semiconductor detector chip (256×256 square pixels with pitch of 55 μm) bump-bonded to a readout chip. Each element of the matrix (pixel) is connected to its respective preamplifier, discriminator and digital counter integrated on the readout chip. Each pixel can independently work in one of three modes: Medipix mode (the counter counts incoming particles), Timepix mode (the counter works as a timer and measures the time when the particle is detected) and time over threshold (TOT) mode. The Timepix device running in the TOT mode measures the charge collected in each pixel. As the device contains 65,536 independent channels and as their responses can never be identical, it is necessary to perform an energy calibration for each of them. A single particle often generates a signal in a cluster of adjacent pixels. This is because the charge generated by the particle spreads out during the charge collection process and it can be collected finally by several adjacent pixels forming the cluster. Utilization of the Timepix chip based on measurement of heavy charged particle energy loss has been published in the literature (Jakubek et al., 2008). The Timepix device for the estimation of radon progenies using the filter method with measurement of alpha decay products only is discussed elsewhere (Bulanek et al., 2015, 2014).

The basic setup of the Timepix with the FitPix interface consists of setting the clock frequency, bias voltage, threshold equalization, and then energy per-pixel calibration. Threshold equalization is a procedure which makes the overall threshold as homogenous as possible. With the Pixelman software (Turecek et al., 2011), the procedure is automatic and uses noise pulses to find the distribution thresholds for each adjustment value, then selects for each pixel a suitable threshold adjustment that is as near as possible to the average of the means of threshold distributions (see http://aladdin.utef.cvut.cz/ofat/others/Pixelman/Pixelman_manual.html#Thresholdequalization). In some cases it's not possible to equalize all pixels; some of them give a permanent signal and some of them are “dead”. In such cases the calibration procedure allows for such responses to be ignored.

In the preliminary energy calibration, performed outside NIRS, the Timepix (the device used later in this study) was irradiated by a multi-energy calibration source constructed as a combination of an isotopic gamma source and a set of XRF (X-ray fluorescence) materials with the energy range from 6 to 60 keV. (Jakubek, 2011).

However, isotopes in radon and thoron chains decay with emission of alpha particles with energy higher than 5 MeV. Therefore the calibration of the Timepix for alpha particles in the range from 5 to 9 MeV is much more complicated because the total charge can only be revealed by making a summation of all fractional charges, i.e. by determination of the cluster volume not for single pixel clusters as for gamma or X-ray radiation. An example of the cluster volume generated by a single alpha particle from ^{241}Am (5.485 MeV) is shown in Fig. 1.

The above-mentioned limitations were taken into account, and the dependence between alpha particle energy and response of Timepix device was evaluated at the NIRS. Alpha standard sources of ^{241}Am (particle energy of 5.485 MeV with activity of 1 kBq) and ^{210}Po (5.305 MeV with activity of 0.4 kBq) were used for evaluating the energy dependence in the range below 5.5 MeV. As for the range above 5.5 MeV radon (Ichitsubo et al., 2004) and thoron (Sorimachi et al., 2010) chambers were utilized. In this experiment, the Timepix device collected alpha particles emitted from radon progenies, i.e. ^{214}Po (7.7 MeV) and ^{218}Po (6.00 MeV) as well as from thoron progenies, i.e. ^{212}Bi (6.05 MeV) and ^{212}Po (8.8 MeV).

All stages of the experiment were carried out in the TOT mode. The measurement was performed with the threshold set to 330 and with a sensor bias voltage of 50 V. The clock frequency was set to 10 MHz and the constant current source parameter I_{krum} was set to its minimal value of 1. The data acquisition and processing of clusters was done using Pixelman software described earlier.

Before the energy calibration and efficiency estimation, the distortion of spectra regarding bias voltage in the range from 7.5 to 100 V was checked using the ^{241}Am and ^{210}Po sources. This check was done because the experiment described by (Jakubek et al., 2008) using alpha particles had shown a dramatically growing cluster height if bias voltage was higher than 40 V. They attributed this phenomenon to a problem with the constant current source parameter I_{krum}, which does not work properly for large collected charge.

In this study the Timepix chip was placed in a vacuum desiccator (volume, 6.9 dm^3; vacuum conditions, ~700 mm Hg) which was used as an exposure chamber. Results of the spectra distortion experiment utilizing the ^{241}Am and ^{210}Po sources are shown in Fig. 2. The log-normal relationship between bias voltage (7.5–100 V) and cluster height was observed for ^{241}Am and also for ^{210}Po. It was concluded that the phenomenon of distorted pixels was not detected and I_{krum} as well as other DAC (digital-to-analog converter) parameters of the Timepix chip were set up properly.

In order to find the optimal DAC configuration, the influence of bias voltage variation on cluster size and height was analyzed.