PERSONAL RADIATION DETECTOR γ-TRACER GT2-1 WITH A CdZnTe DETECTOR[*]

S. Gushchin[**]**, V. Ivanov, A. Loutchanski, V. Ogorodniks**

ZRF RITEC SIA, Riga, Latvia

Abstract. *The Personal Radiation Detector (PRD) γ-Tracer GT2-1 was developed with a focus on gamma-radiation searches and detection and offers a gamma-radiation source localization function, enhanced PRD features and the capability of isotope energy pattern analysis. The device complies with general requirements and includes all typical features of PRD-class devices as well as supplementary modes such as multi-channel scaling (MCS), a spectrometer, library-driven analysis and a data logger. The GT2-1 uses a detector module built around a 0.4 cm³ counting-grade planar CdZnTe detector.*

CdZnTe offers high-efficiency gamma-radiation detection for a small detector volume and energy discrimination down to 30 keV. The GT2-1 was designed with power consumption in mind; its typical lifetime after a full battery charge exceeds 600 hours in measurements mode.

Energy compensation techniques are employed for the dose rate calculations. The typical accuracy of the device in the energy range of 30–1500 keV is better than 10% for factory-calibrated devices.

The GT2-1 features a library-driven isotope identification function. Its underlying concept is the use of a library of pre-calibrated user-defined isotope patterns for comparison with the isotope under investigation. The identification algorithm is designed to evaluate the isotope energy pattern match. The execution of the algorithm yields the matching results between the tested isotope and the library in graphical form.

The device's search mode employs a proprietary Background Variation Tracking (BVT) algorithm. The implemented search and gamma-radiation source localization mechanisms facilitate the rapid (1–3 sec) detection of weak gamma-radiation sources with intensities that exceed the background level by a factor of 1.5–3. Analysis of the time intervals between adjacent pulses in the input sequence is used to determine numeric characteristics that are also displayed in a user-friendly graphical form. The dedicated GUI approach and sound capabilities are tailored to facilitate search activities and support the operator in gaining experience with the device.

The dedicated search algorithm implementation allows the device to be used as a homeland security detector by services responsible for the control of the relocation of radioactive materials, such as those at airports, border control checkpoints, and tolls.

Test results for the GT2-1 in search mode are presented.

Key words: *Personal Radiation Detector, PRD, CdZnTe detector, dose rate, dosimeter*

DOI: 10.21175/RadJ.2016.01.08

1. INTRODUCTION

Currently, CdZnTe nuclear radiation detectors of various designs and sizes are widely and successfully used for various applications because of their favorable detection properties, including the ability to operate at room temperatures, high efficiency, good energy resolution, small dimensions and low weight. There are a number of device applications based on these detectors. Among the wide variety of devices that contain CdZnTe detectors, there are compact pocket-sized devices for the detection and measurement of gamma radiation parameters. Conventionally, such devices are divided into several groups that differ in their purposes, namely, Personal Radiation Detectors (PRDs), dosimeters, Spectral Personal Radiation Detectors (SPRDs) and Radiation Identifiers.

The primary task of a PRD is radiation detection, with the intent of raising an alarm in the case of possible radiation threat to an operator or indicating the presence of a radiation source. Modern PRDs are hand-held, lightweight tools that can be kept in a pocket or fixed to the wearer's belt. The inherent ability of such devices to register dose rates allows a PRD to serve as a dosimeter – a device that serves to accurately measure the dose rate and the accumulated dose received by the wearer during a given exposure period. An instrument that is capable of registering and distinguishing gamma-radiation emission energies is known as an identifier tool. Its general purpose is the detection of the presence and the identification of isotopes.

Existing commercially available devices are generally designed on the basis of Geiger-Mueller counters or scintillation detectors (NaI or CsI(Tl)). The primary disadvantage of the devices based on Geiger-Müller counters is their low detection efficiency for gamma radiation, and devices based on scintillation detectors can detect radiation only in a narrow range of dose rates and are rather large in size and low in

---

[*] The paper was presented at the Third International Conference on Radiation and Applications in Various Fields of Research (RAD 2015), Budva, Montenegro, 2015.

[**] Contact: s.gushchin@ritec.lv

mechanical robustness. The use of CdZnTe detectors allows for the achievement of a detection efficiency that is sufficient for most tasks and extends the range of measurable dose rates. Such devices also have a low energy detection threshold; they are sensitive to energies of 20–30 keV and above.

Currently available SPRDs with CdZnTe detectors allow for the identification of radioactive materials based on their gamma-radiation spectra [1, 2]. Spectrometric detectors of various designs with sensitive volumes of 0.5–1.0 cm^3 are used in these devices. These relatively large-volume spectrometric CdZnTe detectors are expensive. The additional cost for these devices is significant because of the detector complexity. Therefore, the use of these devices, despite their high spectrometric performance, is still limited.

CdZnTe detectors have several features that must be taken into account for their successful application. First of these is the strong dependence of the detection efficiency on the energy of the detected gamma radiation and the problem of the tissue equivalence of CdZnTe detectors [3–6]. A special energy-compensated technique must be used for correct dose rate evaluation. Additionally, the strong microphonic effect that occurs in CdZnTe detectors because of their piezoelectric sensitivity must be taken into account. These issues limit and complicate the use of CdZnTe detectors in PRDs and dosimeters for field applications.

Research efforts have resulted in the successful solution of these problems and the implementation of this solution in the commercially available GT2-1 detector. The device integrates the properties of PRDs and personal dosimeters as well as some limited capabilities of radiation identifiers. The GT2-1 was designed based on a reasonably cheap "counting-grade" CdZnTe detector with a planar geometry and a volume of 0.4 cm^3. A unique feature of this device is its search mode for the search for and detection and localization of gamma-radiation sources. Measurements of the true dose rate require energy compensation of the detection efficiency. The applied compensation method uses information regarding the spectral composition of the detected radiation.

In this paper, descriptions of the device and its main features, main operating modes, signal processing algorithms and test results are presented.

Figure 1. Personal Radiation Detector GT2-1.

2. DESCRIPTIONS OF THE MAIN FEATURES AND MODES OF THE GT2-1

The Personal Radiation Detector GT2-1 is a pocket-sized, lightweight instrument for gamma and X-ray radiation measurements built around a solid-state CdZnTe detector. The main parameters of the GT2-1 are summarized in Table 1. The device combines proven measurement characteristics and a rich set of functions and features with the benefits of a low-cost counting-grade planar CdZnTe detector application.

Table 1. Main GT2-1 specifications

Detector type	Counting-grade planar CdZnTe
Detector size	2 cm x 1 cm x 0.2 cm
Energy range	30 keV–3.0 MeV
Dose rate	0.05–2000 μSv/h
Dose	0.05 μSv–10 Sv
Sensitivity to ^{137}Cs	15 cps/μSv/h
Accuracy	± 15%
LCD	98 x 64 pixels
Data recording capacity	up to 3000 entries
Operating time	up to 900 h
PC communication	micro USB
Operating temperature	-20 °C to +50 °C
Weight	200 g

The device's affordable price, freely available suite of PC tools and long duration of continuous operation without the need to recharge provide the user with a professional-class tool with only a moderate budgetary impact. The GT2-1 features professional-grade sensitivity (10 cps at 0.01 μSv/h ^{241}Am), a wide measuring range (5 decades), sensitivity at 30 keV and above, the capability of energy-compensated true dose rate measurements and a rich set of additional features. The selection of CdZnTe provides an extended dynamic range, enhanced accuracy, perfect linearity over 4 decades, a wide temperature range and stability over time [7]. The GT2-1 is depicted in Fig. 1.

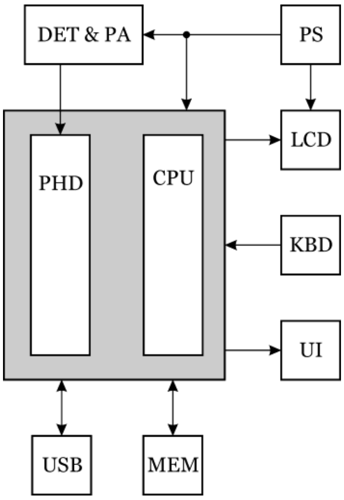

Figure 2. Block diagram of the GT2-1.

A block diagram of the GT2-1 is shown in Fig. 2.

The detector module (DET & PA) consists of a planar "counting-grade" CdZnTe detector and a charge-sensitive preamplifier. The detector dimensions of 2 cm x 1 cm x 0.2 cm have been found to be optimal for sensitivity and budgetary reasons, though other sizes are also feasible. The electrical pulses that are generated in the detector module as a result of the interaction of photon radiation with the solid-state detector material are then supplied to the data acquisition module and the processor (PHD, CPU). The results are processed by the CPU and stored in non-volatile memory (MEM). The run-time processing includes alarm generation (UI) and control checks (KBD). The device's power subsystem comprises a high-voltage generator and a linear drop-down stabilizer (PS) powered by a rechargeable Li-ion battery.

This device architecture and the use of a low-power Cortex M0+ CPU allows for long-duration battery operation in the regular measurement mode and enables the implementation of additional functions typically associated with expensive professional tools. The selection of a non-spectrometric solid-state CdZnTe detector instead of a conventional scintillator or a Geiger-Müller counter provides a perfect compromise among sensitivity, linearity, and time stability with an additional set of functions for a lower price.

The dose rate calculation with energy compensation for the non-spectrometric CdZnTe detector is based on the techniques suggested in [6]. The key advantage of this technique is its estimation of the power distribution across seven preset energy ranges and its analytic calculation of the dose rate using polynomial coefficients.

A dedicated search mode is also implemented to facilitate the detection and localization of artificial radiation sources.

The ability to perform a spectrum match analysis of gamma ray spectra is an optional tool that is available as a dedicated mode of the GT2-1 to facilitate isotopic identification based on the results of previous learning procedures.

Three acquisition modes are designed to address various operation conditions and to tailor the intrinsic algorithm parameters to particular measurement conditions. These are Accuracy, Balanced and Response. The Accuracy mode is characterized by greater integration time constants, the Response mode is better suited for device operation in relatively rapidly changing radiation fields, and the Balanced mode is the default mode with balanced parameters.

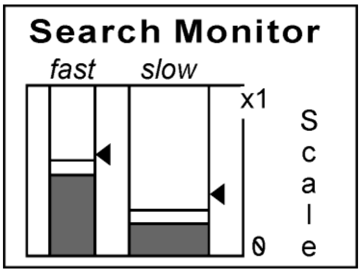

Fig. 3. Search mode monitor window.

In measurement mode, the GT2-1 supports either dose rate or count rate measurements. All acquired results are stored in non-volatile memory and may be accessed as logs read using the GT2 Configurator PC software, browsed and converted to spreadsheet format.

The alarm subsystem processes both dose rate and count rate run-time checks when the GT2-1 is in measurement mode. The alarm signal functions include sound (audible and earphones), two-color LEDs, and vibration.

On par with conventional mechanical countermeasures, the GT2-1 introduces a detector condition supervisor firmware module to suppress the microphonic effect and to avoid the influence of electromagnetic fields.

In the multi-channel scaling mode, the count rate of the detected pulses as a function of time is recorded. Both dose- and count-rate indicators are supported.

All essential parameters can be quickly accessed via the Quick Set Menu and Main Menu options, and the full set of run-time parameters may be modified using the free PC software tool GT2 Configurator.

3. SEARCH MODE ALGORITHM

The implementation of a search mode associated with nuclear instruments is not a straightforward task because of the associated need to process a number of signals in real time with the limited computation and power resources of a battery-powered PRD. The inherently stochastic nature of the signals and the intensive statistical mathematical methods needed for search criterion evaluation pose a particular challenge.

Regular search methods based on variations in count rate are best suited for devices with a large detector volume. Such methods are not feasible for portable devices because of size, weight and budgetary reasons. Instead, a new method based on timing analysis has been adopted and tested. The key assumption that drives its implementation is that its fault detection tolerance is notably higher than that of the regular measurement mode. Tailored visualization techniques are introduced to ease operator search practices and to improve the fault-detection-to-missed-detection ratio for weak sources.

The dedicated search mode of the GT2-1 is built on a proprietary Background Variation Tracking (BVT) algorithm. In this mode, the device focuses on detecting and localizing activity and offers an intuitive visual tool to enable the operator to reliably find sources of artificial radiation. An effective algorithm for the suppression of natural background variations employs both a static period distribution model and actual learning results. The operator has the option to manually select the sensitivity grade and thus optimize the tradeoff between the sensitivity and the fault detection rate.

The key mathematical principle underlying search mode operation is a moving average [8] inter-pulse period estimation and a subsequent statistical processing step. The history of the run-time acquisition results is allocated to volatile memory tables. The two vertical bars show the results of the input count rate analysis and the BVT algorithm processing. The Fast response channel is related to the movements of the operator and indicates direction, whereas the Slow response channel is related to the proximity of the active source (see Fig. 3.). Some preliminary training exercises and practice sessions are required. The specific parameters of the algorithm were determined by conducting field tests with several persons and evaluating the optimal parameters based on the best results. To address a wide range of possible initial background levels, the system offers manual controls – the buttons labeled Scale Up and Scale Down. Note that in search mode, the GT2-1 automatically modifies the integration time when the input count rate increases.

4. SPECTRUM MATCH MODE AND ISOTOPE ID

Budgetary requirements drive PRD vendors to use rather low-volume "counting-grade" detectors. This limitation makes the implementation of spectrum classification modes difficult because the available spectra have poor statistics and resolution and therefore lack the required information. However, certain spectrum processing techniques allow for isotope evaluation with relaxed time constraints and a limited set of reliably and simultaneously distinguishable isotopes [7]. The modified approach implemented in the GT2-1 realizes spectral comparisons using weighting coefficients. The implementation of this method as a dedicated device mode offers the user greater flexibility in practical nuclide identification. Based on preliminary investigations, the GT2-1 incorporates a proprietary low-resource radioactive isotope identification algorithm for a certain number of isotopes based on seven channels of region-of-interest (ROI) information. Effective background elimination ensures input count rates of 20–2000 cps for the detected isotope and significantly increases the sensitivity of the method.

The key principle underlying this approach, in contrast to that offered in [7], is the comparison of corresponding ROI ratios between adjacent channels and the use of a background compensation process when calculating the compensated counts based on the average inter-pulse period for each ROI channel. This combined approach yields improved isotope spectrum matching performance, although it involves additional preparation steps and careful calibration to ensure an acceptable confidence level.

A typical procedure begins with laboratory preparation: background calibration and reference isotope calibration for each isotope type to be used in the subsequent identification analysis. The identification performance depends on the corresponding user libraries and their quality. Therefore, for a given GT2-1 device, a library of reference spectra must be collected by the operator beforehand.

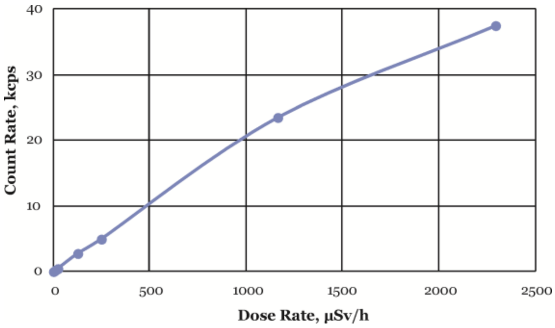

Fig. 4 Measured count rate versus dose rate.

In general, not only single isotopes but also random mixtures of isotopes can be used for library calibration. There are four isolated locations available in the non-volatile memory of the GT2-1 that are intended for such mixtures or unknown isotopes, which are referred to as X1 – X4 in the system menu. When the GT2-1 is operating in identification mode, the spectrum under investigation is first identified as belonging to one of three classes – low, moderate or high energy. This classification is necessary to increase the evaluation speed and generates useful identification criteria. In the second stage, the collected spectra are repeatedly compared with all active library entries, and isotope-tailored weighting coefficients (factory defaults) are applied to emphasize any notable spectral features. The ultimate results of the comparison are then passed to the statistical processing module, which yields correlation values proportional to the matching levels. The reference spectrum for which the best correlation is found is indicated on the display as the detected isotope type. Additional supplementary output informs the operator regarding the relevant match quality as a percentage, the current count rate and the volume of collected statistics used for the determination.

The spectrum match mode implemented in the GT2-1 is not a full-featured, reliable tool; rather, it has obvious limitations imposed by the detector resolution. However, it may be a reasonable compromise for users who are interested in only a certain limited number of known isotope types and are subject to budgetary constraints.

5. TEST RESULTS

The accuracy certification for the GT2-1 was performed in the certified Secondary Standard Dosimetry Laboratory (Salaspils, Latvia). The calibration procedure was performed at a radiation test facility using a panoramic gamma irradiator capable of outputting 0.9–2300 µSv/h for ^{137}Cs and 6.6–160 µSv/h for ^{60}Co.

The tests indicated good accuracy in the dose rate measurements for the ^{137}Cs source in the measured range of 0.9–890 µSv/h and for the ^{60}Co source in the measured range of 12–155 µSv/h. The typical accuracy of factory-calibrated devices was found to be within 8% over 3 decades of load variation for both isotopes.

Fig. 4 shows the dependence of the recorded count rate on the dose rate deduced from the measurements

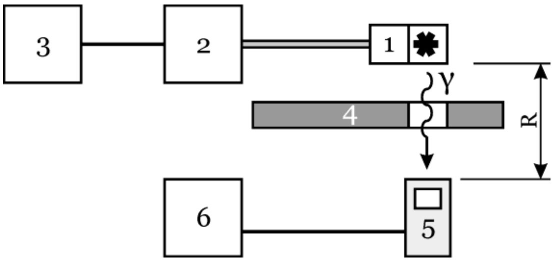

Fig. 5 Schematic diagram of the test setup: 1 – ^{137}Cs gamma-radiation source mounted in a holder, 2 – reciprocating motion mechanism, 3 – control unit, 4 – lead shield, 5 – PRD GT2-1, 6 – Personal Computer.

of the ^{137}Cs source. Good linearity of the measured count rates in a dose rate range of up to 1500 μSv/h was observed.

To systematically test and verify the search capabilities of the GT2-1, a measuring test setup was constructed. A schematic diagram of the test setup is provided in Fig. 5. A source of gamma radiation (^{137}Cs, activity of 60 kBq) was placed in a moving holder (1). The holder was coupled to a reciprocating mechanism (2) controlled by a control unit (3). The radiation source in the holder could move between at stop at one of the two following positions: hidden behind a 50 mm lead shield (4) or set in front of a slit of 50 mm in width (with the source radiating toward the GT2-1 device (5) through the slit). The movement speed of the source was approximately 0.1 m/sec. As the source moved, evidence of device exposure did not appear immediately. The rise time of the recorded dose rate level was within 0.15–0.2 sec. The control unit allowed for the measurement of the time intervals during which the source was behind the shield or in the engaged position. The number of basic tests performed in a single trial could be specified and controlled through the setup of the control unit. The irradiation dose rate at the point of interest could be adjusted as desired by modifying the distance R between the source and the GT2-1 device. In the tests, we performed observations at dose rate levels from the natural background of 0.10 μSv/h up to a factor of five (based on the average count-rate ratio) above the background level. The count rate recorded by the tool at the background level was approximately 2 cps (^{137}Cs).

Each basic test consisted of the following steps: the source was moved to the slit, remained in front of the slit (in the radiation exposure position) for a certain amount of time and then was moved back behind the lead shield. Thus, the device was exposed to the radiation field for a time period T at a preset dose rate level (1.5, 2, 3 or 5 times above the background level). We used a series of basic tests to obtain the necessary statistical information for our trial. Every trial sequence was comprised of 100 identical basic tests. During each basic test, the device was either able to detect the source or not. In either case, the result was sent to the PC for the collection of the statistical information. For each series of tests, the number of successful detections of the sources as a percentage of the total number of basic tests in the series was determined.

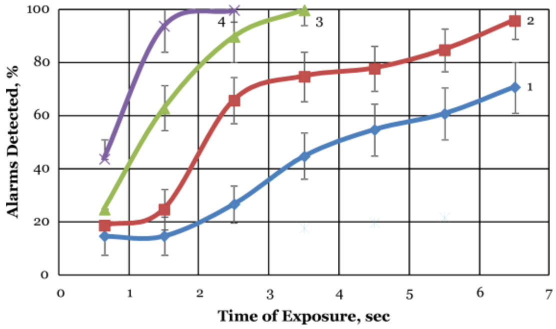

Fig. 6 Number of successful detections as a percentage vs. the radiation exposure time for various dose rates: 1 – 0.15 μSv/h (1.5 times above the background), 2 – 0.2 μSv/h (2 times above the background), 3 – 0.3 μSv/h (3 times above the background), 4 – 0.5 μSv/h (5 times above the background).

The radiation exposure period varied from 0.65 to 7 seconds for the different trials. We had the opportunity to test the various operation modes of the GT2-1, obtain the relevant numerical values and compare them with the parameters of other detecting tools in the same test installation. All tools and supplementary measurement probes were placed at identical reference points with the specified gamma-radiation intensity. The devices were placed at the reference point such that the geometric center of the detector coincided with the reference point.

A trial sequence of 100 basic tests was performed, and the number of warning signals issued was recorded.

Fig. 6 shows the dependence of the number of successful detections of the source (as a percentage) on the radiation exposure period for various dose rate levels. The results indicated that in the search mode scale 1, the GT2-1 achieved a successful detection rate of approximately 70% in the presence of a weak ^{137}Cs radiation source, creating a dose rate at the point of measurement of approximately 0.15 μSv/h (1.5 times the background) for an exposure period of 6–7 seconds.

Moreover, gamma-radiation sources that created higher dose rates were detected by the GT2-1 within a much shorter period of time. A gamma-radiation source with an intensity of 0.20 μSv/h (2 times the background) was detected in 70% of cases during an exposure period of 3–4 seconds, and a source with an intensity of 0.50 μSv/h (5 times the background) was detected within 1 second. At this intensity, a detection rate of 100% was achieved within 2 seconds.

6. CONCLUSIONS

The pocket-sized Personal Radiation Detector GT2-1 was developed based on a planar "counting-grade" CdZnTe detector with the functionality of gamma-radiation dosimetry and is commercially available. The GT2-1 was specifically designed for the detection and localization of gamma-radiation sources.

The use of a rather small-volume CdZnTe detector of 0.4 cm^3 and the implementation of a proprietary custom search algorithm allows for the detection of weak radiation sources within quite short periods of time. Thus, the gamma-radiation produced at a point with a measurement dose rate of approximately 0.20–0.30 μSv/h can be detected within 2–3 seconds in more than 50% of measurements, and a 100% alarm rate can be achieved within 6-7 seconds.

Operation of the device in isotope identification mode using a modified low-resource radionuclide identification algorithm allows for the identification of certain isotopes that are pre-defined in the device memory.

Future efforts in the development of the GT series of PRD will include the integration of a small-sized spectrometric CdZnTe detector and a large-volume counting detector to extend the dynamic range of the measurable dose rates and to approach the isotope identification capabilities of expensive professional systems.

REFERENCES

1. “Spectroscopic personal radiation detector identiFINDER R300,” FLIR Syst., Wilsonville (OR), USA, data sheets. Retrieved from: http://www.flir.com/uploadedFiles/flirGS/Threat_Detection/Radiation_Detection/Products/IdenitiFINDER-300/DS_identiFINDER-R-300-en.pdf
2. “Spectrometric Personal Radiation Detector GalaxRay,” Galaxray, data sheets, 2016. Retrieved from: http://www.galaxray.com/products.html#tabs-tab-title-2.
3. V. Nagarkar, M. Squillante, G. Entine, I. Stern and D. Sharif, “CdTe Detectors in Nuclear Radiation Dosimetry,” *Nucl. Instr. Meth. A*, vol. 322, no. 3, pp. 623–627, Nov., 1992.
4. В.С. Горев, В.А. Кожемякин, О.А. Матвеев, М.Д. Фирсов, А. Х. Хусаинов, Г.К. Шульгович, “Применение детекторов на основе теллурида кадмия в дозиметрии гамма-излучения,” *Приборы и техника Эксперимента*, №. 1, с. 60–64, 1981. (V.S. Gorev, V.A. Kozhemyakin, O.A. Matveev, M.D. Firsov, A.H. Husainov, G.K. Shul’govich, “Cadmium Telluride Based Detectors for Gamma Radiation Dosimetry,” Instruments and Technique of Experiment, no. 1, pp. 60-64, 1981.)
5. В.А. Мокрицкий, О.В. Маслов, О.В. Банзак, “Коррекция зависимости чувствительности CdZnTe-детектора от энергии гамма-излучения,” *Збірник наукових праць Військового інституту, Унів. Тарас Шевченко*, № 39, с. 81–84, 2013. (V.A. Mokrickii, O.V. Maslov, O.V. Banzak, “Correction of Gamma-Ray Energy Dependence Sensitivity of CDZnTe-Detector,” *Monogr. Milit. Inst. Univ. Taras Shevchenko*, no. 39, pp. 81-84, 2013.)
6. Rybka A.V. et al., “Gamma-Radiation Dosimetry with Semiconductor CdTe and CdZnTe Detectors,” *NIM A*, vol. 531, no. 1-2, pp. 147–156, Sep. 2004.
7. R. Arlt et al., “Use of CdZnTe Detectors in Hand-Held and Portable Isotope Identifiers to Detect Illicit Trafficking of Nuclear Material and Radioactive Sources,” *Nucl. Sci. Symp. Conf. Rec., IEEE 2000*, vol.1, pp. 4/18–4/23.
8. Retrieved from: http://www.maths.qmul.ac.uk/~bb/TS_Chapter4_3&4.pdf