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DEVELOPMENT OF A PORTABLE ENERGY SELECTIVE NUCLEAR PROBE USING PIN PHOTODIODE

the author's summary of PhD thesis

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Introduction

Portable isotope selective devices are widely used, such as at environmental radiological monitoring, disaster protection/ of nuclear accident, illegal trade of radioactive materials, inspections of the IAEA Safeguards (Safeguards) and military operations in support of NBC. In Hungary the Army, Paks NPP, the National Food Institute, various research institutes (AERI, NRIRR) and the Directorate for disaster management use dispose portable isotope selective devices.

My thesis primarily deals with equipments used in the military sphere and my research also highlights such applications. At the moment, of the forces going on operations only HAVÁRIA laboratory has isotope selective instruments. Regarding their field applicability, however, these devices have disadvantageous qualities. Having realized this fact, I have started a research to develop a radiation probe with a quality of a better adaptation to field strains, which can provide a good basis for other mobile units, too.

After the NATO accession of the Republic of Hungary, in the period of 2000 and 2009, the radiological reconnaissance ability of the Hungarian Army has significantly improved. Forces were supplied with IH-95 radiation level and contamination meter, the chemical protection special teams were provided with the devices of the modern on-board reconnaissance, first on the VS BRDM-2, later on the VS-BTR armoured cars. Airborne radiological reconnaissance container was initiated, which is suitable for four channel gamma spectroscopy. HAVÁRIA laboratory obtained high-purity germanium semi-conductor detectors, which are suitable for radioactive gamma isotope identification.

The Hungarian Army has to meet the requirements of detection, reconnaissance and identification defined by NATO SIRA handbook. One of the most important of these requirements is that special sub forces must be provided with a field-portable and vehicle-mounted gamma spectroscope, which is suitable for identifying the most common radioactive isotopes on the field.

Devices capable of a quick, on-the-spot detection of low level (but still dangerous for life) gamma-ray isotopes emitted in the field are already existing. Although these devices using modern multichannel analyzer and semi-conductor detectors are very expensive, they require careful handling and technical expertise. Furthermore, in many cases their military application faces difficulties. Spectrometers applying scintillation detector are also able to diagnose the

contamination isotope-selectively, but for their operation a photomultiplier tube is needed, which is reactive to terrain conditions (temperature, mechanical strains, etc.). With the miniaturization of these devices and electronics, significant reduction in size and energy consumption can be reached; furthermore, the devices would be much more resistant to mechanical damages.

A special semi-conductor device, that is the PIN photodiode, could be a promising replacement for the photomultiplier tube. Of the most advantageous properties of the PIN diode the followings can be mentioned: its consumption, quantum efficiency, insensitivity to magnetic field, but perhaps the most conspicuous of all is its small size. Since PIN diode is a simple pn junction, if the layers are not damaged it is undestroyable, in contrast to the photoelectron multipliers, which have a number of sensitive components.

When these photodiodes are optically coupled to a scintillation crystal, each scintillation light pulse will generate a small charge pulse in the diode which can be measured with a charge sensitive pre-amplifier. A suitable electronic and multichannel analyser makes it possible to record the gamma spectrum of the ray source, so the more common gamma isotopes could be detected as well. The difficulties of the analysis caused by the lower resolution of the scintillation detector can be solved by using special evaluating methods. Therefore, a device consisting of scintillator crystal, PIN photodiode, signal condition amplifier is cheap, applicable to terrain conditions, and easy to use because the installed special algorithm seems to be possible to develop.

PIN diode detectors integrated with solid scintillation crystal are already on the market, but they are primarily used for research purposes, and are specifically developed for laboratory conditions and are therefore not suitable for military duty.

Based on the hypothesis mentioned above, a detector system containing a scintillator crystal, PIN diode, a signal amplifier detector can be developed, which is smaller, cheaper and more suitable for field use in contrast to the devices already existing in the system and used for gamma isotope detection.

Research objectives

The general objective of my research is (i) to estimate the tool park suitable for gamma isotope detection currently used in the Hungarian Army, from the aspect of field application. On the basis of the assessment, (ii) to determine the important gauge boundary conditions of an ideal on-the-field-device, and from hence (iii) to develop the system plan of a new detector, which is more adaptive to field circumstances, capable of a selective detection of dangerous multicomponent gamma radioactive isotopes and contains PIN diode.

Within that I have identified the following specific objectives:

a) To analyse the in-situ gamma isotope selective detectors of the Hungarian Army units from the aspect of their usability on the field, and the basis of these to define the main boundary conditions of the ideal on-the-field detective device.
b) To analyse the on-the-field adaptability of PIN photodiode, as a device capable of photon detection and to create the system plan of a device applicable under field conditions.
c) To make the noise calculation of the detector system applying PIN photodiode, to plan and create its optimal electronic circuit.
d) To create the prototype of the new measuring system and to analyse its energy selectivity to prove the possibility of isotope selectivity measurement.

Research methods

In the course of my research my essential considerations were to comply with the principles of scientific justification, systematic approaches, observations and synthesis-oriented conclusions. I intended to achieve my objectives by analysing relating literature and other documents, as well as by my own experience, experimental measurements and making conclusions. I have studied the regulations and methodology concerning radiological reconnaissance, searched for, analysed and critically assessed relating books, notes and studies. I reviewed and compared similar systems and methods currently in use in Hungary. During my research I used the results of my consultations with associates working in HAVÁRIA laboratory.

Summary

In the first part of the I. chapter, I defined what is meant by isotope selective measurement. I introduced the two techniques also used in NATO for measurement, which are suitable for identifying gamma isotopes under field conditions.
In chapter I, I established that the various subunits of the Hungarian Army are equipped with isotope selective devices applicable for on-the-field usage, however, after a detailed analysis of these instruments I have come to the conclusion that the individual tools have some disadvantages due to their development, portability and measuring procedures. I have found that there is a need for a compact isotope device working under field conditions that is easy to handle, does not require a power supply network, is not needed to be connected to a computer for spectrum evaluation ,easily portable and can be installed.

In chapter II., I summarized the physical properties of semiconductor devices, which make it suitable for the detection of nuclear radiations. I examined what happens when a charged particle slams into the emptied layer of the semi-conductor. I observed that PIN photodiode, as a special semi-conductor device, is a suitable base for creating isotope selective detector. I have compared the photomultiplier tubes used in scintillation measurement technique with the PIN photodiode, outlining their advantages and disadvantages. Taken these characteristics into consideration I have concluded that under heavier field constraints, PIN photographed is more suitable for amplifying photons arriving from the scintillation crystal.

In chapter III., I have outlined the architecture of the PIN photodiode detector system that I had examined, and analysed the individual parts, as charge-sensitive pre-amplifier and shaper main amplifier and their electrical properties. I deduced, why the charge-sensitive pre-amplifier used as a sensor in PIN diode is capable of radiation-induced charge extraction. I examined how each elements of the pre-amplifier can influence the definition of the complete information content of the useful sign. Since the amplitude of the detector signal amplitude is in the mV range, which is the amplitude level of the electrical- and noise sources coming from the outside world, there is a great need for the accurate noise analysis of the system. Therefore I have made a complete noise calculation in the system and I have reached the appropriate time constants and electronic parameters. At the end of the chapter, using the aforementioned parameters, and through the implementation of a specific circuit I have proved that with the

connection of a CsI(Tl) scintillator crystal to a PIN diode we are capable of isotope selective detection of nuclear radiation.

In the first point of chapter IV., I determined the electrical properties of the system, which affect its detection ability. I completed a test of the equivalent noise charge of the detector, and thus using the established shaper time I checked the system's signal response with the help of radiation sources. Using an oscilloscope I found that the system produces different amplitudes of signals under the time constant set before, and at the measurement of the radiation source a significant increase in counts was experienced. System detection was completed using radioactive sources in this chapter. I recorded spectra, performed the energy calibration and examined the dependence of the results of different settings. It is proved that the system is suitable for quality defined isotopes.

New scientific results

1) With the detailed analysis of radionuclide identifying instruments used in HAVARIA laboratory of The Hungarian Army I have ascertained the need for a device, that is portable, compact, adaptable under field conditions and usable for implementing isotope selective measurement , which is easy to handle, does not require a power supply network and easy to install. Analysing the light sensor characteristics of a PIN photodiode I have also established, that by ransoming the scintillation gamma spectrometers photomultiplier tube unit, the device can provide a basis for that purpose.

2) I have developed the theoretical structure of a detector unit which consists of a CsI(Tl) scintillator crystal and a PIN photodiode, determined the electrical parameters of the detector and its associated system, and completed a full noise calculation on each of its components. So using the electrical parameters optimized like that, I have created the system design of a detector applicable under field conditions.

3) I have made a specimen detector consisting of CsI(Tl) scintillator crystal and PIN photodiode. With tests using radioactive sources, I have proved that the energy selectivity of the detector is appropriate for the execution of isotope measurements.

Suggestions

The final result of my dissertation is an isotope selective detector system which can be used under field conditions. I believe that the new system can be employed in all places, where the size, consumption, compact design is more important than the quantitative determination of isotope composition. In the future, if we connect the detector to a compact, small-scale multi-channel analyser (digital signal processor), we attach a screen, and the plating is adapted to field conditions, we will get a device that with its robustness and energy selectivity may rival with the devices used at the moment.

The device resulting from my research can be applicable as the followings:

- as a detector at the units of the Hungarian Army, who do not possess isotope selective device, as well as at the HAVÁRIA units on standby;
- due to its small size and consumption, as a detector with changeable geometry with its connection of various detectors. It could be outstandingly used in situations, where the contaminated objects are difficult to measure and we are not only concerned about its contamination, but also the source of the contamination. For this measurement a more complicated value system is needed, which can at present only be available in laboratories;
- as a device for the monitoring of the incoming air of aerators, the examination of its contamination and isotope composition. The advantages of its small size can be used in such tight places as in the ventilation system of protected bases;
- as an extension for scout ability of land robots. Nowadays, the adaptation of robots for military and catastrophe protection purposes are well known. Such a land device (UVG) equipped with the detector introduced above, would result an efficient device, which is capable of reconnaissance without endangering human life.