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Gamma Spectroscopy Prototype Design to Identify Radioactive Elements

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Abstrak

Sistem identifikasi unsur radioaktif menggunakan metode spektroskopi gamma single-channel analizer (SCA). Namun proses produksi spektrum tersebut masih cukup lama karena harus melalui proses manual dengan memindai energinya; salah satu unsur radioaktif lainnya adalah spektroskopi gamma. Penelitian ini bertujuan untuk mengembangkan sebuah prototipe spektroskopi gamma yang memungkinkan identifikasi unsur radioaktif. Dalam penelitian ini, peneliti menggunakan metode eksperimen dengan merancang prototipe spektroskopi gamma yang terdiri dari detektor NaI(TL) berdiameter 2,5 cm yang dilengkapi dengan photomultiplier, modul tegangan tinggi, modul preamp, modul pulse shaping, modul sample hold, dan microcontroller Atmega dengan tampilan LCD beresolusi 128 × 64. Hasil pengujian prototipe ini dilakukan dengan berbagai sampel radioaktif. Peneliti berhasil mengidentifikasi unsur radioaktif dengan mengukur pulsa listrik yang dihasilkan oleh detektor NaI (TL). Background counting, yang merupakan hasil cacahan dari detektor tanpa bahan radioaktif, berhasil diidentifikasi dan dihilangkan. Pola distribusi memiliki sifat acak, resolusi energi spektroskopi terdiri dari 1024 kanal, dan waktu counting dapat diatur sesuai kebutuhan melalui tombol reset. Temuan utama dari penelitian ini adalah bahwa prototipe spektroskopi gamma mampu memberikan gambaran yang jelas tentang spektrum energi radiasi nuklir, yang memungkinkan identifikasi unsur radioaktif dengan baik. Hasil penelitian ini memiliki implikasi penting dalam bidang identifikasi unsur radioaktif dan dapat digunakan dalam berbagai aplikasi ilmiah dan industri yang melibatkan radiasi nuklir.

***Kata kunci**: Unsur Radioaktif, Radiasi Gamma,* Prototipe Spectroscopy Gamma

Abstract

The identification system for radioactive elements used the single-channel analyzer (SCA) gamma spectroscopy method. However, the process of producing the spectrum was still quite long because it had to go through the process manually by scanning its energy; one of the other radioactive elements is gamma spectroscopy. This research aims to develop a prototype gamma spectroscopy that allows the identification of radioactive elements. In this study, researchers used an experimental method by designing a gamma spectroscopy prototype consisting of a 2.5 cm diameter NaI(TL) detector equipped with a photomultiplier, high voltage module, preamp module, pulse shaping module, sample hold module, and Atmega microcontroller with an LCD display resolution of 128 × 64. The results of testing this prototype were carried out with various radioactive samples. Researchers managed to identify radioactive elements by measuring electrical pulses produced by NaI(TL) detectors. Background counting, which is the result of enumeration from detectors without radioactive material, was identified and eliminated. The distribution pattern has a random nature, the energy resolution of the spectroscopy consists of 1024 channels, and the counting time can be set as needed via the reset button. The main finding of the study was that the gamma spectroscopy prototype was able to provide a clear picture of the energy spectrum of nuclear radiation, allowing good identification of radioactive elements. The results of this study have important implications in the field of identification of radioactive elements and can be used in a variety of scientific and industrial applications involving nuclear radiation.

Keywords: Radioactive Elements, Gamma Radiation, Gamma Spectroscopy Prototype

1. INTRODUCTION

A decaying radioactive source emits particles at random. These particles have a specific energy. One of them is the γ particle which cannot be seen with the naked human

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eye, so a detector is needed to detect the energy emitted by a radioactive source. There are many types of radioactive source radiation detectors (Kumar et al., 2019; A. M. Wang et al., 2019). To be able to display the spectrum of nuclear radiation energy, we need a sensor that is not only able to measure the intensity of the radiation entering it but also must be able to provide a linear stimulus with the energy of the radiation entering it, for example, a NaI(TL) stimulation detector. This detector is included in the type of scintillation detector. In the Scintillation detector, radiation is converted into Flashes of light. The radiation interacts with the scintillation material. The scintillator absorbs all the kinetic energy of the radiation to produce pulses of light whose number is proportional to the power of the radiation (Dervishi et al., 2019; Ersan & Sarikurt, 2019).

Initially, the identification system for radioactive elements used the single-channel analyzer (SCA) gamma spectroscopy method. However, the process of producing the spectrum was still quite long because it had to go through the process manually by scanning its energy; one of the other radioactive elements is gamma spectroscopy (Craven et al., 2022; Malaka, 2019; Takada et al., 2022). Spectroscopy gamma multichannel analyzer method The energy scanning process can be carried out quickly with the help of a microcontroller by looking at the shape of the spectrum of the measurement results; this can be done through the introduction of spectrum images of each radioactive element so that it can be directly used to identify radioactive elements (Aryanti et al., 2022; Caridi et al., 2016; Liu et al., 2022; Sulyaev et al., 2013).

Spectroscopy is the science that studies the properties and properties of matter by using light, sound, or particles that are emitted, absorbed, and reflected by the material. This is also known as the science that studies how light and matter interact (Meza Ramirez et al., 2021; Stevie & Donley, 2020). Meanwhile, gamma spectroscopy or MCA (Multi-Channel Analyzer) is a detector composed of a NaI(TL) detector, a high voltage module, a preamplifier module, a pulse shaping module, a sample & hold module, a microcontroller module along with a local LCD it is equipped with serial communication for to other devices such as IoT (Hamer et al., 2019; Rammah et al., 2020). The gamma rays that enter the detector interact with the atoms of the scintillator material to produce a spectrum of the photoelectric effect energy region, a spectrum of the Compton scattering energy region, a spectrum of the energy region of the production pair, and an energy spectrum of radioactive elements (Estienne et al., 2014; Piveteau et al., 2020; Siegbahn, 2012).

One of the dominant spectra is the radioactive element, where the energy of the radioactive source will emit a random α or β or γ particle. The particles have a certain energy. β and γ particles cannot be seen with the naked human eye, so a detector is needed to detect the energy emitted by the radioactive source (Amoyal et al., 2021; Gilmore, 2008; Paschalis et al., 2013). There are several types of radiation detectors for radioactive sources, including gas-filled detectors, ionization chamber detectors, proportional detectors, Geiger-Muller detectors, and scintillation detectors (García-Toraño et al., 2015; He et al., 2019; Roy et al., 2019).

Continuously these radioactive elements will receive exposure to ionizing radiation which is always present in nature. It is necessary to calibrate the energy first (Chierici et al., 2022; Kramm et al., 2019; Saudi et al., 2020). Using a NaI(TL) detector, the pulse height generated by the detector will be proportional to the energy of the gamma radiation entering the detector. A certain channel number will record the pulse height in a certain window, which is proportional to the energy of gamma radiation. Therefore, the channel number unit can be changed by constructing a straight-line equation between the channel number and the radiation energy. Using a source of gamma-emitting radiation whose energies have been identified is necessary (Mardiana et al., 2005; Putri et al., 2021; Torowati et al., 2021). This radiation comes from natural sources such as radium (Ra) in water, potassium (K) in living tissue, and other radioactive elements. To be able to display the energy spectrum of nuclear radiation, a detector is needed that is not only able to measure the intensity of the radiation entering it but also must be able to provide a linear stimulus with the energy of the radiation entering it, one of which is the design a prototype of a gamma spectroscopy (Buonanno et al., 2020; Muthmainnah et al., 2020; Reynolds et al., 2020). This research aims to design a prototype of a gamma spectroscopy device to identify elements and test results. The detector used in this activity is a scintillation / NaI(TL) type detector Ludlum 44-2.

2. METHODS

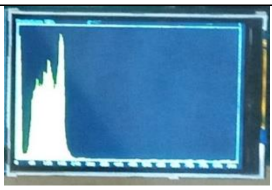
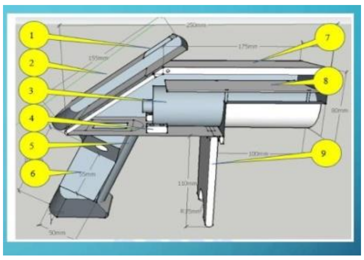
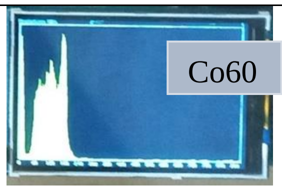
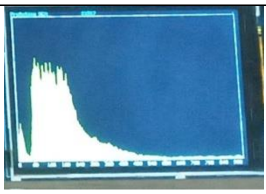
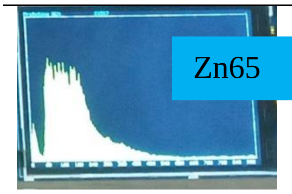
The research method in the design of gamma spectroscopy prototypes for the identification of radioactive elements is carried out in several stages, namely: (1) Developing a prototype design concept consisting of selecting a detector that is sensitive to gamma chosen by Ludlum 44-2, choosing a high voltage module to operate stably at a voltage of 900 to 1000 DC volts according to detector specifications with a module width of 2.5 cm, choice of preamp module suitable for detector type Ludlum 44-2 with a module size of 2.5 cm wide, choice of amplifier module and pulse shaping so that it can be used to form gausian measured pulses with a module size of 2.5 cm wide, the choice of the sample hold module to be used for sampling the electrical pulses corresponding to the highest point of radioactive elemental energy is then integrated with a microcontroller to be displayed on an LCD and transmitted via serial communication to a computer to be displayed on a wide screen and the data can be stored, as well as the power supply module; (2) Prepare Detailed Designs for placing various types of electronic components, starting from resistors, op-amps, TTL, microcontrollers, and capacitors, the result of which is a PCB layout ready to be filled in by these electronic components; (3) Integration of finished components of electronic modules; (4) Individual testing of electronic modules; (5) Integration of all electronic modules into gamma spectroscopy prototypes; (6) Testing of gamma spectroscopy prototypes for identification of radioactive gamma elements.

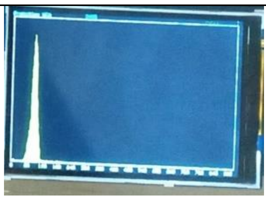
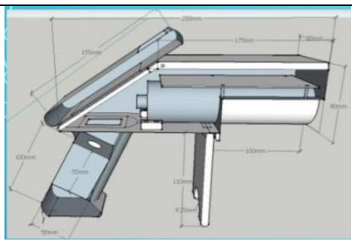
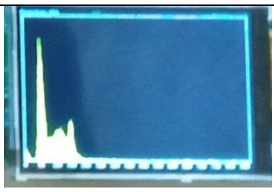
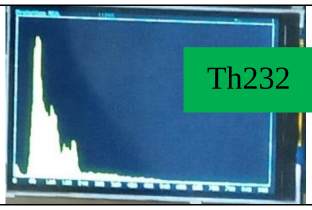
3. RESULTS AND DISCUSSION

Result

The results of this study are presented in Table 1, and Figure 1.

Table 1. Test Result

Spectrum Display	Handheld Packaging Form	Results of Identification of Radioactive Elements
		
		

Spectrum Display	Handheld Packaging Form	Results of Identification of Radioactive Elements
		
		
		

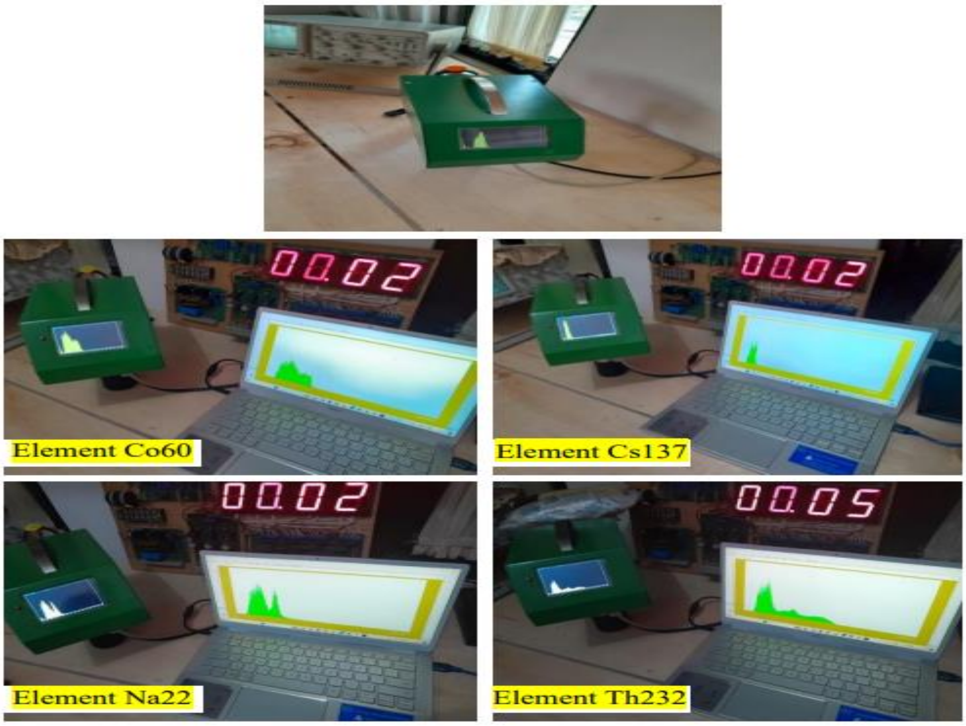


Figure 2. Documentation of Test Results

Discussion

The result of the flash of light from the NaI(TL) crystal is received by the photomultiplier tube (PMT), then multiplied and converted into electrons in the PMT, which generates electrical pulses, which an electronic processor then processes. The detector used in the activity was a scintillation/NaI(TL) type Ludlum 44-2 detector. The working principle of the Photomultiplier Tube contained in the detector receives a voltage supply from the high voltage module of 1000 Volt dc (working voltage of the photomultiplier Tube), the NaI(TL) crystal receives gamma radiation, and the interaction with the radiation produces a flash of light then the flash of light is received by the photomultiplier tube to be converted into electrical pulses which are multiplied and amplified by the Pre-Amplifier module. The vibrations of electric pulses that come out of the Pre-Amplifier are then shaped in such a way by the Pulse Shaping module to become symmetrical electrical pulses in the form of a Gaussian. The amplitude is set to be in the region of 0 Volts to 5 Volts peak pulses for various types of radioactive elemental energy. In this case, a 2000 Kev element is equivalent to a 5 Volt peak pulse for power, while a 100 Kev essential point is equivalent to a 0 Volt peak pulse. After the electrical pulse is formed correctly, it is fed to the sample hold module, which the microcontroller controls to be processed into digital data.

In addition, the Microcontroller Atmega328P-1 controls the work function of the sample hold module in sequence; the Microcontroller issues the ADC logic. The initial status is in High condition, meaning there has not been a conversion process from the incoming electrical pulses to the sample hold module (Hacke et al., 2018; Jordan et al., 2020). The Microcontroller simultaneously issues Clear Fet and Clear logic. SH to the Hold sample module to ensure the value of the conversion data capacitor voltage is Empty, then the Microcontroller gives the ADC logic Convertible Status in Low condition means that an electric pulse appears, the maximum voltage is Hold, simultaneously issues an interrupt pulse to the Microcontroller to convert to digital via pin2 microcontroller Atmega328P-1, the converted digital data is input into the energy memory and displayed on the horizontal axis LCD after the data is sent to the Atmega32P-2 microcontroller via serial communication, as gamma energy information, where the number of gamma energy channels provided is 1024 channels for various heights Gamma pulses that appear according to the type of radioactive element. Each type of radioactive element also has certain energy peaks to produce a specific spectrum of energy. Besides being displayed on the LCD, the converted digital data is also sent to an external computer via serial communication to be processed and displayed on the computer monitor screen (Park, 2016; Ye et al., 2018).

Radioactive elements have different properties from one another but come from the same source (Thabayneh & Jazzar, 2013; Zlobina et al., 2022). One of the beneficial properties of radioactive elements is their high penetrating power. The ionizing power of a radioactive element is the ability of a radioactive element to attract electrons from the atoms in its path, which affects the penetration strength of this radioactive element. Particle ionization power γ has the lowest power (Charlesby, 2016; C. Wang et al., 2022). The stronger the power, the more atoms of radioactive elements will use their energy to ionize. The design was carried out using a scintillation / NaI(TL) detector type Ludlum 44-2, a material that can emit light twinkles when interacting with γ particles. The surface of the scintillation detector consists of a layer of NaI(TL) which emits a flash of light when it interacts with gamma radiation.

The experiment begins by counting air as a background counter as presented in Table 1 and Figure 1. Like gamma rays, photons moving through the air are electromagnetic waves—the gamma rays cut through the NaI(TL) detector layer (Bhattacharyya et al., 2021; Cebrián et al., 2012). Pair production, the Compton effect, or the photoelectric effect, will occur when photons strike the matter. All three events produce electrons through electron excitation. A photon, or twinkling, and a γ-ray, produce one electron each. When the electron shell of an atom is excited, a vacancy occurs. As a result, deexcitation occurs, which always produces a photon. These photons enter a photoelectric screen, causing the photoelectric effect, which consumes the energy of the photons and produces electrons. PMT has many diodes or dynodes. When an electron hits the first diode, which has a large potential difference, the electrons will be doubled or multiplied to generate more electrons from that diode and the next diode (Cebrián et al., 2012; Ozur & Proskurovsky, 2018). The preamplifier amplifier will receive the electron output from the gamma rays hitting the scintillation detector and then convert them into voltage pulses. Because the amplitude of the voltage pulses from the preamp is very small (in the order of millivolts), the amplifier circuit produces voltage pulses of around a few volts. These voltage pulses are displayed as a histogram by the gamma spectroscopy method of the Multi-Channel Analyzer, or MCA. The pulse height (CH) is equivalent to the energy of the gamma radiation from a particular radioactive element.

Subsequent experiments by pressing the reset button and alternately placing standard radioactive sources such as Co60, Cs137, Zn65, Na22, and Th232 and pressing the reset button before changing the standard source, monitoring can be done in parallel with the computer display after the computer has installed the viewer processing program.

Based on several experiments carried out alternately, it has produced a spectrum of a specific spectroscopy prototype design for each of these radioactive elements. In line with previous research stated that the scintillation detector can detect γ rays in units of keV (Qi, Wang, et al., 2022; Qi, Zhao, et al., 2022). The NaI(TL) detector has a resolution of 24% in capturing γ 137Cs and 60Co radiation energy. And is used as a source in determining the power of the γ radiation emitted by 137Ba. Another study conducted by cvv (Qian et al, 2019) concluded that by using a NaI(TL) detector, the pulse height generated by the sensor would be proportional to the γ-radiation energy entering the detector. The enumeration was carried out on two radioactive sources, Co-60 and Cs-137. In addition, Co-60s measurements were carried out at seven different HV (High Voltage) values, 650, 670, 690 and 710 Volts, while Cs-137 was at 650 Volts. The observation results show that the energy resolution of γ radiation is greater than that of β radiation energy. Some of the things that were obtained from this test, namely background counting is known as the counting results from detectors without radioactive material, and is used to reduce the counts produced by detectors without radioactive material, the pattern used for distribution is random, the spectroscopic energy resolution occupies 1024 channels. The counting time is set as desired with the facility of pressing the reset button, and the spectrum pattern used for each element is very clear so that it can be used to identify these radioactive elements.

4. CONCLUSION

Based on the design and tests that have been carried out, several conclusions can be drawn, namely background counting is also known as counting results from detectors without radioactive material. It is used to reduce counts produced by detectors without radioactive material. The distribution pattern is random. The resolution of the spectroscopic energy occupies 1024 channels, and the counting time is set as desired by pressing the reset button. The spectrum pattern of each element is very clear so that it can be used to identify radioactive elements.

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