King Fahd University of Petroleum and Minerals
Department of Physics
Physics 503 - Term 142

Experiment #3 Report

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Prompt Gamma-ray Neutron Activation Analysis (PGNAA)

Graduate Laboratory (Phys - 503) term 142

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1 Abstract

Detection of toxic element in water solution is required by many fields. This report demonstrates the mechanism of PGNAA technique in detecting and measuring the concentration of nickel contamination in water solution. Water solution containing 1.2, 2.8, 8.2, and 9.4 wt% of nickel were used to find the relation between nickel concentration and the number of detected gamma rays. Having this relation, we can approximate the concentration of nickel in nickel contaminated water solution.

2 Introduction

In performing elemental analysis of bulk sample, Prompt Gamma-ray Neutron Activation Analysis (PGNAA) has been widely used in many fields such as industrial, environmental, medical, civil engineering, and so on. This technique is widely used because it is a non-destructive method, and the chemical form and shape of the sample are relatively unimportant. Moreover, in situ analysis might be performed by utilizing portable neutron generator [1].

PGNAA is also commonly used to detect water contamination in many industries such as petroleum, pharmacy, agriculture, and many others. In this case, PGNAA technique was used to detect nickel contamination in water. Nickel is mostly used in fabrication of stainless steel products. Nickel also used in other industries such as rechargeable batteries, catalysts, foundry products, etc.

Most of the time, industrial wastes are in the form of liquid. If this industrial wastes are not treated properly, they may have contaminated ground water. Some side effects of having too large uptake quantities of nickel [2]:

- Higher chances of development of lung cancer, nose cancer, larynx cancer, and prostate cancer
- Lung embolism
- Respiratory failure
- Birth defects
- Asthma and chronic bronchitis
- Heart disorders

Therefore, nickel concentration levels monitoring in such industrial disposal is required.

PGNAA is performed by continuously radiating the sample with neutrons. The constituent elements of the sample will absorb some of the neutrons and emit prompt gamma rays. The emitted gamma rays are then measured by the detector which will count the number of gamma rays and analyze their energies.

The analysis relies on unique elemental signatures. Each element emits a characteristic gamma ray energy as it returns to its stable state. Each element also has different tendency to interact with neutrons. The gamma rays intensity is proportional the number of atoms, which then can be used to calculate the concentration of an element in the analyzed sample. So based on this several consideration we can identify and quantify the elemental constituents of the sample [3].

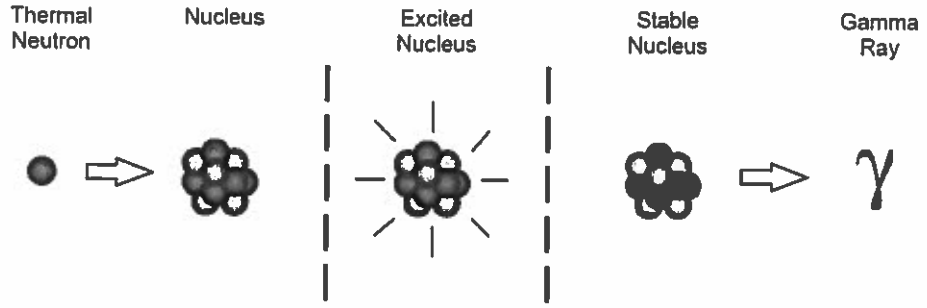

Figure 1: *Schematic representation of gamma rays production in thermal neutron capture (TNC) reactions. [3].*

The gamma rays production can be achieved via thermal neutron capture (TNC) reactions or fast neutron inelastic scattering (NIS) reactions. In this case, thermal neutron capture is chosen. This method is ideally suited for element with high cross section of thermal neutron capture such as mercury, cadmium, boron, etc [1].

The purpose of this experiment is to demonstrate PGNAA capability and mechanism to measure nickel concentration which is a toxic element in water solution.

3 Experimental Details

The experiments was performed using portable neutron generator type MP320 which produces a pulse beam of 2.5 MeV neutron. The neutron is generated through D(d,n) reaction using 70 μA beam of 70 keV deuteron. The deuteron pulse had a width of 5ns and a frequency of 250Hz. BGO (Bismuth Germanium Oxide) detector with 125 mm diameter and 125 mm height was used to count the gamma rays number and analyze their energy. BGO detector has high intrinsic efficiency at higher energy and very fast detection response. Moreover, BGO detector has strong neutron radiation resistance. However, BGO has poor conversion efficiency which results in bad energy resolution. Therefore, BGO is ideal for high energy and high rate gamma ray measurement that outweighing considerations of energy resolution [4].

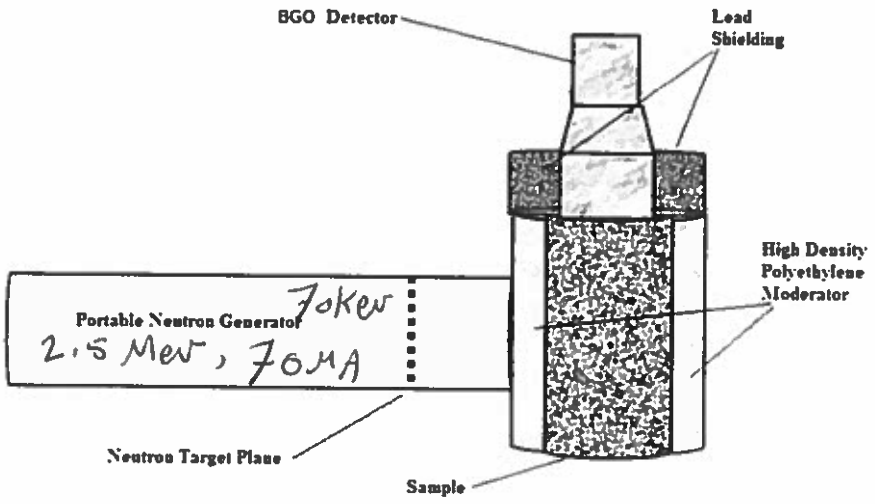

Figure 2: *Schematic diagram of the experimental setup. The main parts of the setup consists of the neutron generator, BGO detector, and polyethylene moderator. Moderator was used to reduce the neutron energy.*

Energy resolution is a parameter that indicate the detector capability to differentiate two or more gamma rays whose energy are very close to each other. This properties of

detector can be seen from the peak of the spectrum. Detectors with good energy resolution have sharp peak while the ones with bad energy resolution have broad peak.

Moderator was used to reduce the energy of fast neutron (2.5 MeV) to the energy of thermal neutron (2.5 meV). The moderator was placed adjacent to the neutron target plane of the portable neutron generator. The moderator has cylindrical cavity and the sample was placed inside it. 3 mm thick lead shielding and 50 mm thick neutron shielding are also used on the surrounding of the gamma ray detector to prevent unwanted gamma rays and neutron from reaching the detector. The neutron shielding was made of a mixture of paraffin and lithium carbonate mixed in equal weight proportions [5].

The samples used in this experiment can be seen in table 1. In this experiment, four water samples containing 1.2, 2.8, 8.2, and 9.4 wt% of nickel were used. These samples with known concentration were measured and it will be used to obtain relation between gamma rays number and the unknown concentration of nickel in the water sample.

Table 1: List of samples information that were used in this experiment.

Number	Chemical Solution	Molarity (mole)	Nickel Concentration (%)
1	NiBr	0.2	1.2
2	NiBr	0.5	2.8
3	$Ni(NO_3)_2$	1.4	8.2
4	$Ni(NO_3)_2$	1.6	9.4

The detector was connected to preamplifier to minimize the source of noise and convert the gamma rays to electrical signal which was send to an amplifier circuit in the control room. The amplifier circuit increases the power of the signal and an analogue to digital converter (ADC) converts the signal to digital number that represents the amount of gamma rays and linear gate stretcher was used to stretch a gated fast pulse to slow pulse. After that,it was connected to multichannel buffer which is connected to the PC where we can observe and record the data.

In this experiment, five measurements were performed. The first one is measurement without using any sample to obtain background spectrum, to calibrate the amplifier, and

to obtain the relation between channel number and gamma rays energy using hydrogen peak. And then, the measurements with four samples were performed with different acquisition time for each samples. The acquisition times were decided spontaneously by observing the deviation in the spectra from the PC. When the deviation had reached less than 10 %, the measurement then was stopped.

4 Results and Discussion

The acquired data that was observed in the PC was showing the number of gamma rays in terms of channel number. A calibration was needed to obtain the relation between channel number and the energy of gamma rays. A calibration was performed by fitting the peak of known element to its energy. In this experiment, the peak of hydrogen was used. The hydrogen that was detected came from the polyethylene moderator.

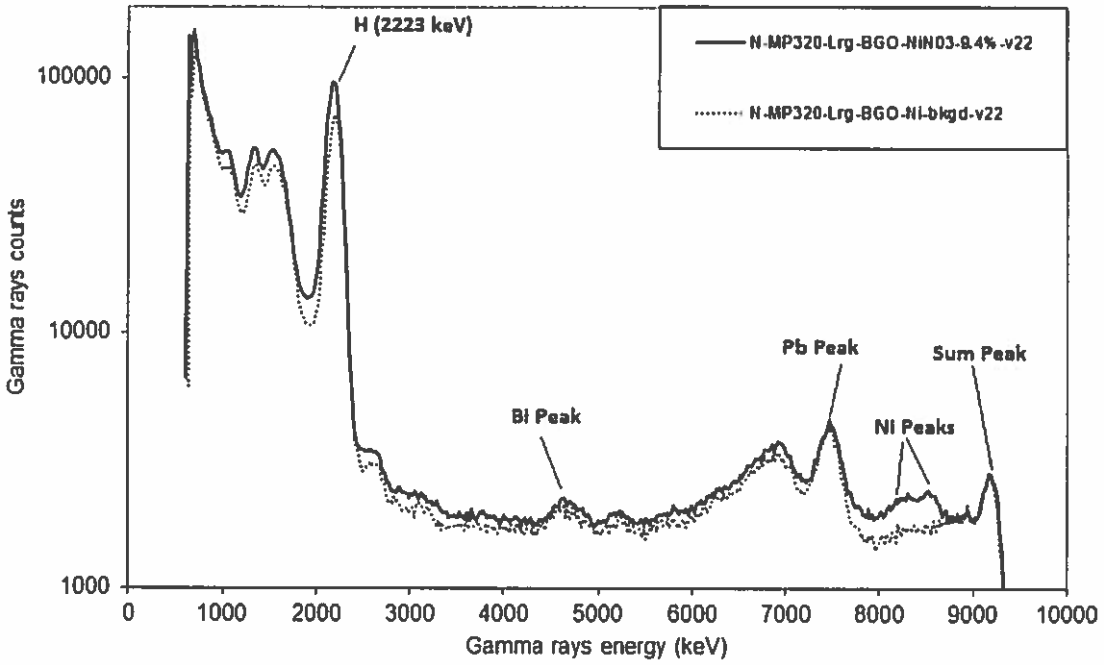

Figure 3: *Prompt gamma-ray experimental pulse height spectrum from a nickel solution sample. The background gamma-ray spectrum without the sample is superimposed to compare the sample influence on the spectrum and also to normalized the spectrum with nickel contamination.*

It was known that the energy of hydrogen gamma rays are 2223 keV. From the raw data it was observed that hydrogen peak was located at channel number 112. From here, we can find the relation between channel number and the gamma rays energy. We obtained that, **1 channel number = 19.85 eV**. Having this relation, all spectrum with

Point is not enough.

respect to the channel number were converted to spectrum with respect to the energy.

In figure 3, we can see all elements detected gamma rays spectra. It shows that the elements come not only from the sample but also from the from the detector (Pb, Bi) and the moderator. These other peaks that contributing to the spectra are considered as the background peaks. Background peaks were used to normalized each of the spectra because background peaks do not depend on the existence of the sample. In this case, the spectra from each sample with different concentration of nickel were normalized and then compared to each other (figure 4).

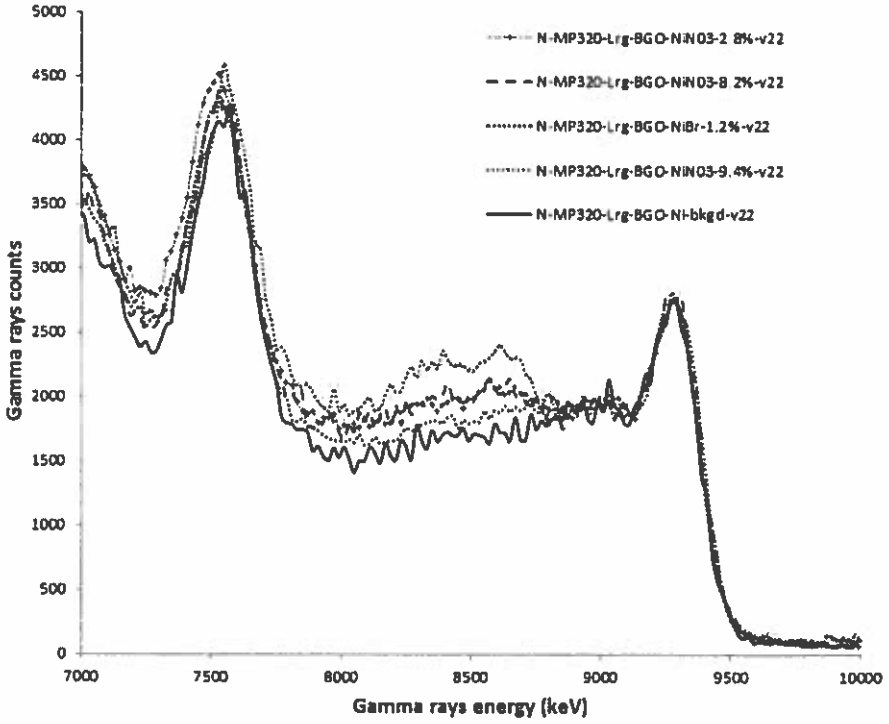

Figure 4: *Comparison of prompt gamma rays spectra from each samples containing 1.2, 2.8, 8.2, and 9.4 wt% nickel and the background (without sample). The area of interest is between the energy of 7700 keV until 9000 keV where we expected to see the peak of nickel.*

Our purpose here is to find the relation between the counts of gamma rays and the concentration of the nickel. It is known that the peaks of nickel can be found at energy

about 8.5 MeV and 8.9 MeV. Because BGO detector was used in this experiment, which has bad energy resolution at high energy, these peaks of nickel cannot be clearly observed. Therefore, an area of interest between 7.7 MeV until 9 MeV was chosen to observe the sample influences to the spectra in this area.

In figure 4, we can see the difference spectra of nickel peaks for sample prepared with 1.2, 2.8, 8.2, and 9.4 wt% nickel concentration. The background spectrum is also superimposed to normalized each spectrum with nickel contamination. The total number of gamma rays in our area of interest is increasing when we have more nickel contamination in the sample.

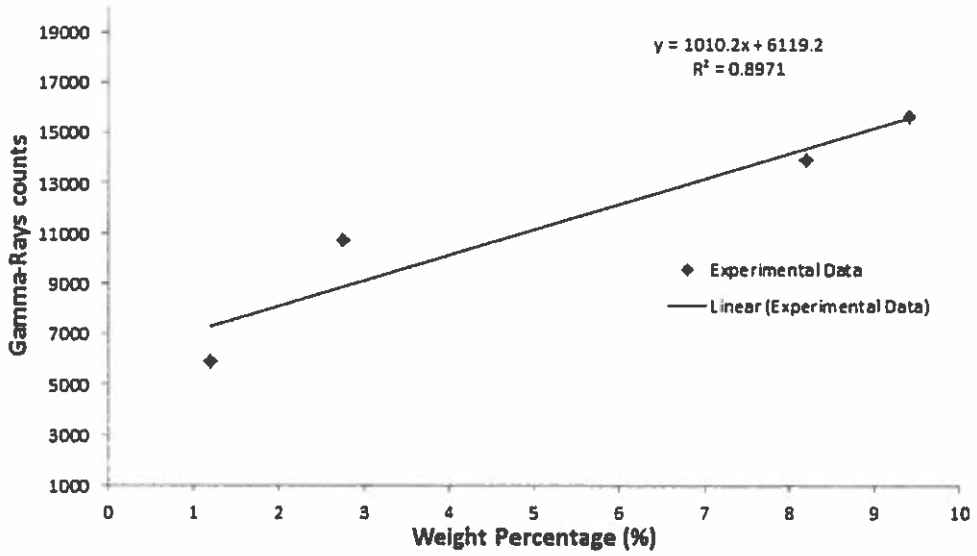

Figure 5: *Relation between total number of prompt gamma rays of the spectra with sample in our area of interest and the nickel concentration in the sample. The total number of prompt gamma rays here were generated by subtracting the background contribution from each of the spectra. The linear fitting was used for approximating the concentration of nickel when the number of prompt gamma rays is known.*

The relation between the total number of prompt gamma rays and the nickel concentration then was plotted (5). Linear fitting was also shown in the figure to approximate nickel concentration when the number of prompt gamma ray is known.

5 Conclusions

PGNAA technique has been used to find the relation between nickel concentration in water solution and the gamma rays number detected by BGO detector. The measurements were carried out with water samples containing 1.2, 2.8, 8.2 and 9.4 wt% of nickel.

It was found that higher concentration of nickel resulting more number of gamma rays were detected. The mathematical relation between nickel concentration and gamma rays number is approximated by linear fitting of the experimental data.

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