King Fahd University of Petroleum and Minerals

Physics Department

Physics 503 - Graduate Laboratory - Term 142

3rd report

Prompt Gamma-ray Neutron Activation Analysis of CrO_3 Water Samples Using BGO Detector and a Portable Neutron Generator

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Extra Work

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Tab Points for report (for assigned tasks) = 20

Bonus Points = 5 for energy Resolution Measurement

Table of Contents

Abstract

High energy capture gamma rays (2-9 MeV) induced from 7.5, 11.4 and 16 % weight ratio of Cr/H_2O samples were tested. A portable pulsed neutron generator and a high density polyethylene moderator were used to produce thermal neutrons. A bismuth germinate $Bi_4Ge_3O_{12}$ (BGO) detector was used to detect the induced prompt gamma rays. Four chromium peaks at energies of 6646, 7100, 7274 and 7938 keV were observed in the spectrum. The integrated intensity of these four peaks plotted versus gamma ray energy, which is known as the calibration curve. The energy resolution was then computed for the prompt gamma rays peaks present in the spectra. A sharp decrease in it was observed at higher energies.

I. Introduction

Prompt Gamma-ray Neutron Activation analysis is an analytical technique used to determine the constituting elements concentrations. Prompt gamma-ray neutron activation analysis (PGNAA) is a non-destructive, in-situ technique that is capable of measuring multielements concentrations in bulk and liquid samples. PGNAA has wide applications in industry, mining quality control, building construction and concrete corrosion, and medical sciences and environmental sciences.

In this technique, the sample is first bombarded with neutron beams. The process of neutrons interaction with the material is called nuclear capture, in which elements nuclei are excited to higher states. Then, the elements nuclei relax and emit gamma rays in two processes, as shown in Figure 1. In the first process, prompt gamma-ray is emitted and the elements decay to the lowest energy state in about 10^{-14} - 10^{-9} seconds after excitation giving energy in the order of 1-10 MeV. Then, the nuclei become either stable or radioactive. The second process is a slow radioactive decay, and it produces beta particles and delayed gamma rays radiation. In Prompt Gamma Neutron activation Analysis (PGNAA), prompt gamma rays are used to determine the constituting elements and their concentrations. After that, prompt gamma rays energies and intensities are measured by a detector through the photoelectric effect. Then, prompt gamma rays energies and intensities are converted to an electrical signals and sent to the computer to be analyzed. Each element has finger-print gamma rays emission which were compared with the emitted gamma rays to test the element existence. Then, elements concentrations are determined from the emitted gamma rays peaks intensities. Good resolution detector is capable of distinguishing between the different gamma rays. High resolution detectors are required for samples with low energy prompt gamma-rays while intense neutron source is required for detection of elements with low

neutron capture or scattering cross section. However, the interference between the sample and the detector increases the background noise and decreases the detector sensitivity.

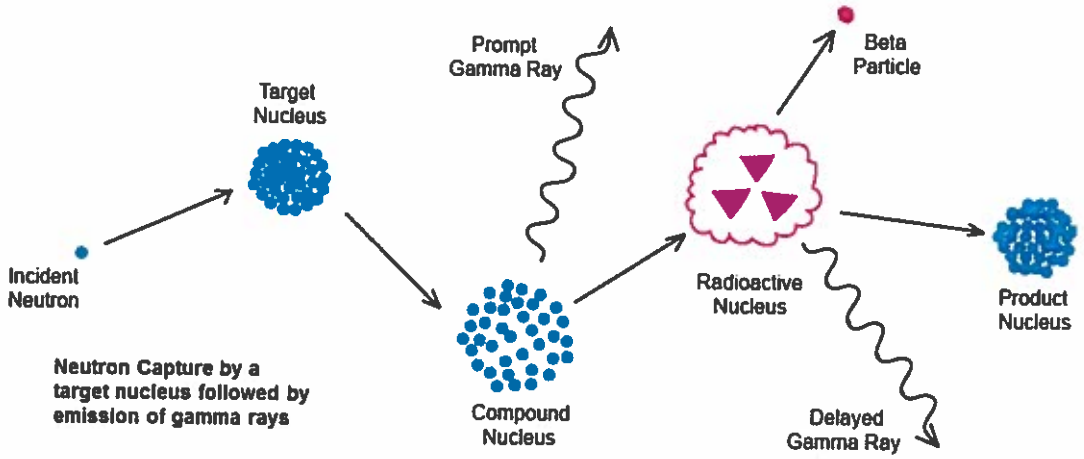

Figure 1. Nuclear decay Process and Prompt Gamma Ray Emission

II. Experimental Methods

A. Sample preparation

The prompt gamma-ray yields from chromium trioxide CrO_3 water samples were tested using PGNAA. Three one litter CrO_3 water solutions of Cr/H_2O weight ratio of 7.5, 11.4 and 16 % were prepared from 4 mol/L CrO_3 water solution by dilution. The experiment on each sample was run for about 90 minutes.

B. Experiment setup

The setup of the PGNAA experiment is shown in Figure 2-3. A portable neutron generator model MP320 was used to generate pulses of 2.5 MeV neutrons beam. A cylindrical modulator of high density polyethylene moderator to decelerate the generated neutrons and convert their energy to thermal energy. The moderator had a central cylindrical cavity of 12 cm diameter to accommodate a specimen and a thickness of 7 cm. The detector was covered

from the sides with a 3mm thick lead layer in order to shield the detector from the undesired gamma-rays and neutrons coming from the environment. The axis of neutron beam coming from the neutron generator was perpendicular on to the moderator cylinder axis, while the detector longitudinal axis was along the moderator axis. The sample was inserted in the moderator such that the bottle axis is on the moderator cylinder axis. The BGO detector was coupled to a fast photomultiplier to amplify the output signal. Also detector had a built in integrated preamplifier to process the signals before sending to the computer. However, BGO detector has poor energy resolution, it is preferably used in neutron activation studies due to higher radiation hardness and larger photo peak-efficiency.

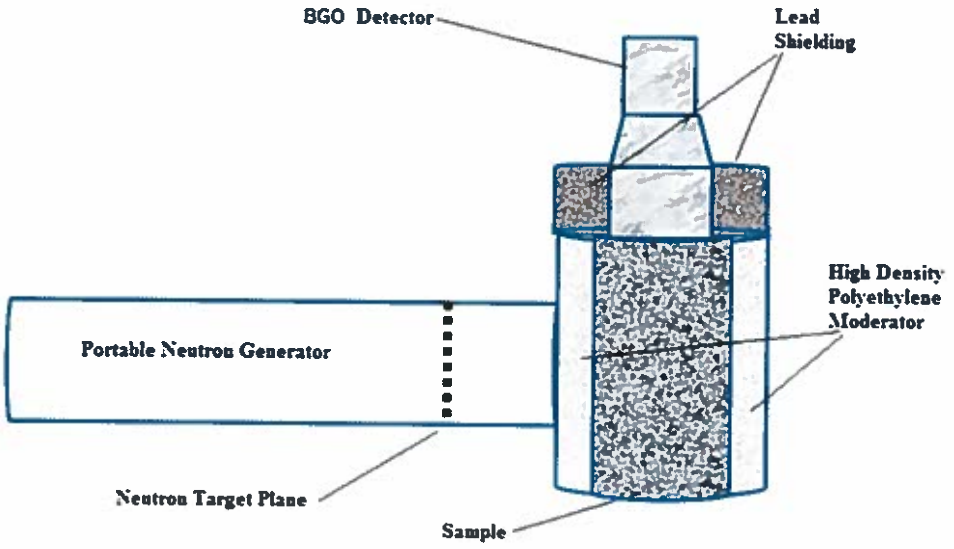

Figure 2: the PGNAA experiment setup

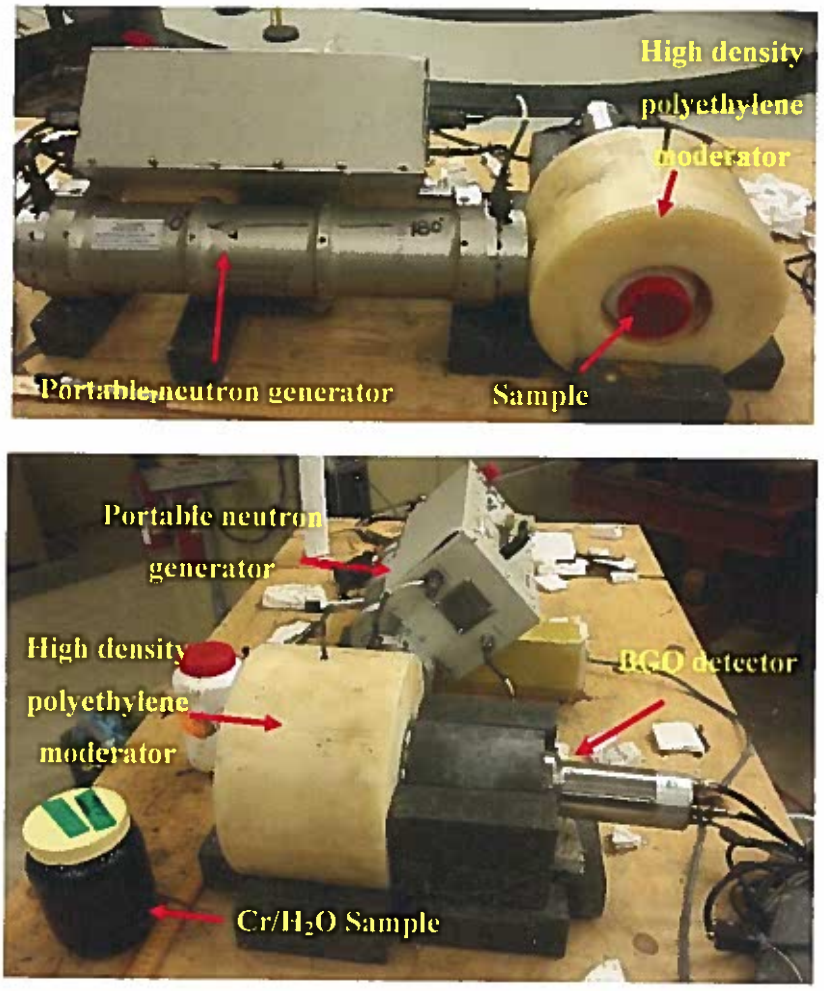

Figure 3: a real view of PGNAA experiment setup

C. Excitation source

Neutrons were produced in a portable neutron generator by the fusion of the accelerated deuterons with stationery deuterons, producing helium isotopes ^{3}He.

$$D + D \rightarrow n + {}^3He \qquad E_n = 2.5 \text{ MeV}$$

The portable neutron generator created a pulsed beam of 2.5 MeV neutrons from deuterons beam of 70 *keV*, 70 μA beam. The deuteron pulse had a width of 5 ns and a frequency of 250 Hz. Gamma-ray detectors vary in energy resolution varying over broad ranges. Bismuth germinate $Bi_4Ge_3O_{12}$ (BGO) detector has energy resolution of about ~ 10%.

III. Results and Discussion

First, the experiment was run with no sample inserted in the moderator to record the background spectrum. This step was important to differentiate between the sample gamma rays peaks and the BGO and noise peaks. Prompt Gamma rays were induced due to the thermal neutron capture in the sample and detector, and they were recorded through the photoelectric effect. A full spectrum of prompt gamma rays was recorded for each sample and the BGO detector background in the range 2000-9000 keV. Figure 4 shows the prompt gamma rays induced from a chromium trioxide solution with 16% Cr/H_2O weight ratio. The energy spectrum below 2000 KeV showed high background noise and thus was rejected. Table 1 shows the elements that correspond to the observed gamma rays peaks in the region 2000-9000 keV and the cross section area corresponding to each gamma ray peak. The right end gamma ray peak is the sum peak due to BGO detector. The spectrum showed peaks corresponding to the elements that exist in the BGO detector and the Cr/H_2O samples, namely Bismuth Bi, Germanium Ge, Hydrogen H and Chromium Cr.

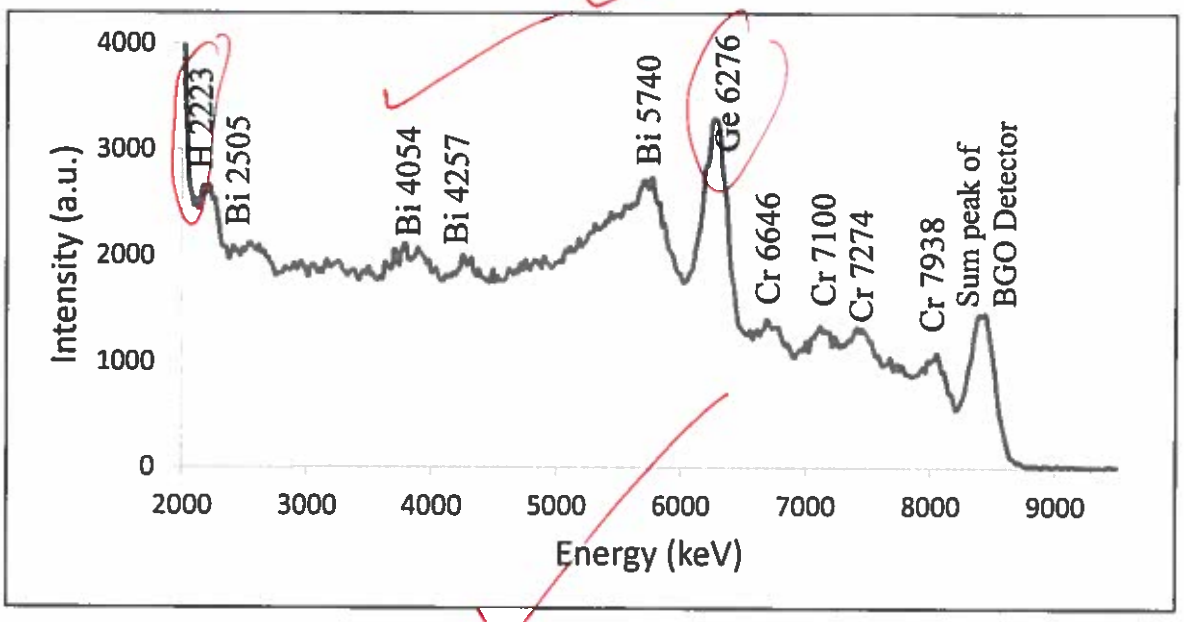

Figure 4: prompt gamma ray spectrum of Cr sample with weight ratio of 16 %.

Table 1: prompt gamma rays peaks, their corresponding elements, cross section, FWHM and resolution

Element	Gamma ray energy (keV)	Cross section σ(Eγ) (barns)	FWHM KeV	Resolution FWHM/Eγ (%)
H	2223	0.3326	176	7.9
Bi	2505	0.0021	320	12.8
	4054	0.00136	337	8.3
	4257	0.0024	150	3.5
Fe	5920	0.227		
Ge	6276	0.021	205	3.3
Cr	6646	0.183	149	2.2
	7100	0.146	248	3.5
	7374	0.080	220	3.0
	7938	0.424	168	2.1

The intensity of the four peaks 6646, 7100, 7274 and 7938 keV shown in Figure 5 showed a difference after inserting Cr/H_2O samples with weight ratio of 7.5, 11.4 and 16 %, confirming their correspondence to Cr. The maximum concentration at which the detector is saturated was found to be around 20%. Then, the Cr four lines 6646, 7100, 7274 and 7938 keV were used for plotting the calibration curve. The integrated intensity between 6500 keV and 8200 keV is plotted versus Cr/H_2O weight ratio in Figure 6. The calibration equation showed that the intensity axis intercept $6.2*10^4$ is close to the recorded background integrated intensity $6.2*10^4$, 11% percentage difference, which indicates reliable results and correct peaks identification.

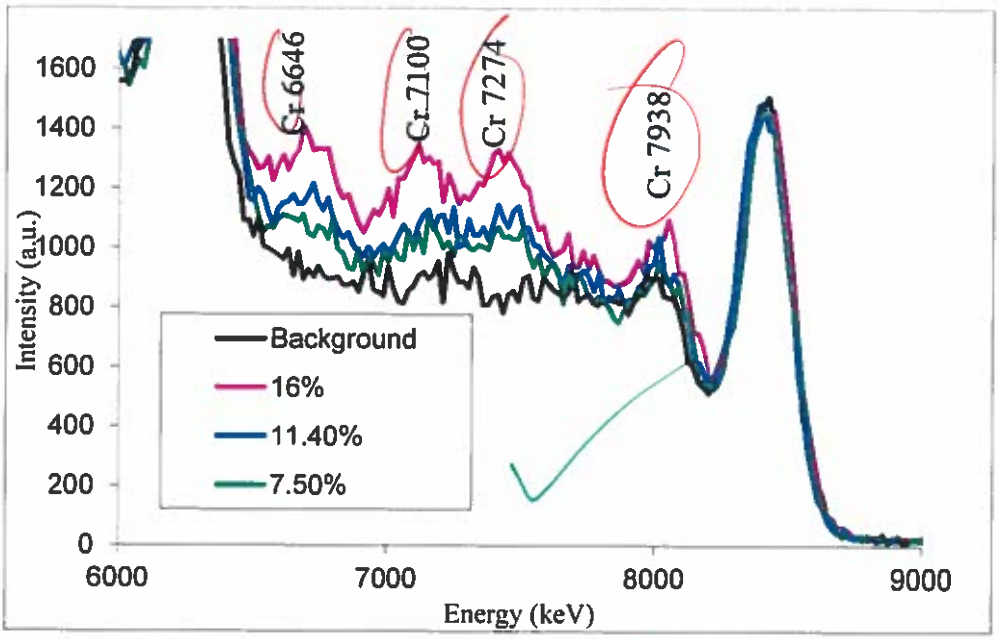

Figure 5: prompt gamma ray spectrum of Cr sample with ~~weight ratio of 16 %~~. 7.5, 11.4 & 16 %. Concentration (wt-%)

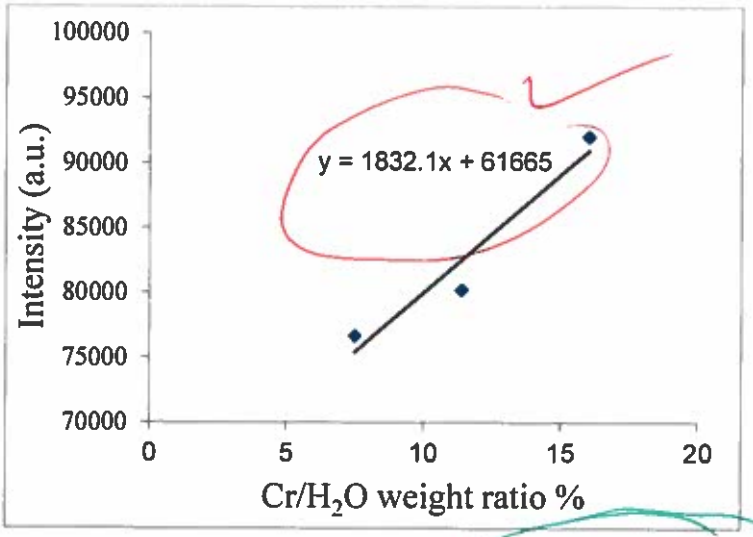

Figure 6: calibration curve of Cr gamma rays peaks integrated intensity in the region 6500-8200 keV. VS Concentration

Figure 7 shows the energy resolution of the BGO detector defined as FWHM/Eγ for the identified prompt gamma rays peaks in Table 1. It is clear that the energy resolution sharply decreases at higher gamma rays energies.

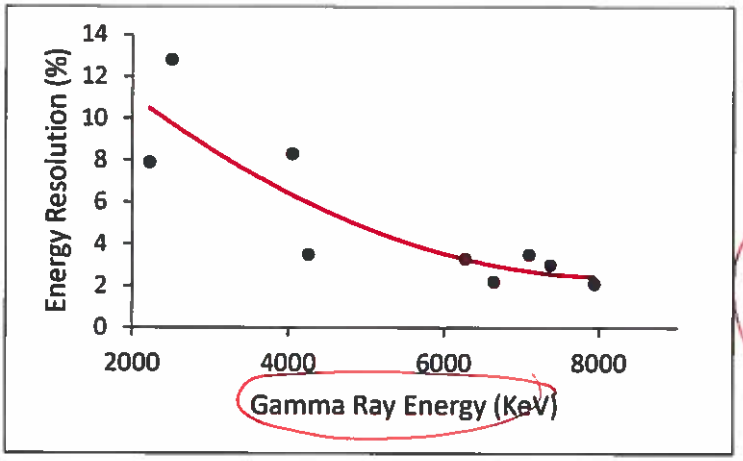

Figure 7: the energy resolution of the prompt gamma rays versus the gamma ray energy.

IV. Conclusion

In this experiment, prompt gamma rays neutron activation analysis was carried out for chromium trioxide samples with Cr/H_2O weight ratio of 7.5, 11.4 and 16 %. A portable pulsed neutron generator was used to excite the samples, and a high density polyethylene moderator was used to produce thermal neutrons and decelerate them. The induced prompt gamma rays due to thermal neutron capture of the sample was detected using a bismuth germinate $Bi_4Ge_3O_{12}$ (BGO) detector. The identified gamma rays peaks were corresponding to Bi, Ge and Cr. The four gamma rays peaks corresponding to Cr 6646, 7100, 7274 and 7938 keV were used for calibration; the integrated intensity of these four peaks were plotted versus Cr/H_2O weight ratio. The energy resolution of the observed peaks were calculated and showed a sharp decrease at higher energy prompt gamma rays.

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