Volume 2 No.5, May 2012 ISSN 2224-3577
International Journal of Science and Technology

http://www.ejournalofsciences.org

The Utilization of Cadmium as Thermal Neutron Filter in the Characterization of Gold Matrix in NIRR-1

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ABSTRACT

Two parameters were systematically varied to optimize the characterization of gold from gold matrix: cadmium thickness ranging from 0.5 to 1.5mm and the time of irradiation of 1 to 30minutes. Gold was observed to be optimally activated at cadmium thickness of 1.0mm and irradiation time of 2minutes. The gamma ray spectrum that resulted from this arrangement was observed to be significantly free from energypeak interference. Other arrangements' energypeak spectra were significantly riddled with interferences and the cadmium became unwieldy as time of irradiation increased.

Keywords: *Cadmium, Gold, Energypeak, Gamma ray spectrum, Interference.*

1. INTRODUCTION

The Nigerian Research Reactor-1 (NIRR-1) does not have a cadmium lining channel to facilitate epithermal neutron activation analysis (ENAA) irradiation. The plan to create cadmium lined channel is however in the pipeline. In the interim, the need for ENAA irradiations as well as analyses is overwhelming and hence the recourse to the use of fabricated cylindrical cadmium shield as thermal neutron filter.

A number of different materials have been considered, even used as thermal neutron filters (cadmium, flex boron, gadolinium, MgO single-crystal, SiO, bismuth, lead, silicon and samarium); however cadmium has displayed strengths unsurpassed in its performance as a thermal neutron filter. It is therefore still the best material to use when the highest degree of accuracy is necessary. In neutron activation applications, it is often prudent to eliminate either the thermal or the epithermal/fast portion of a neutron spectrum with a filter inserted between the source and the target material. For example gold (target) has $Q_0 = 15.7$ ($all\ elements\ with\ Q_0 \geq 10$) are good candidates for ENAA which makes it suitable for ENAA [1], [2]. Cadmium can be used to filter out the thermal neutrons in the characterization of gold from a gold matrix since elements that inhibit gold analysis have Q_0 values usually below ten. Where it is desirable to remove higher energy components, it is common to use two identical samples where one is exposed to the full spectrum and the other is covered in a filter material. Subtracting the filtered response from the unfiltered response enables an estimate of the response to thermal neutrons to be made. This technique is commonly used in neutron activation analysis or to give a measure of the thermal component of a neutron spectrum under investigation. The important properties of the filter are a large absorption cross-section in the stop-band, a small cross-section in the pass-band and a sharp transition between these two regions.

Cadmium has been shown to offer optimal performance at moderate temperatures. It has a large cross-section at low energies, a small cross-section at higher energies and a reasonably sharp transition between the two as depicted by Fig. 1.

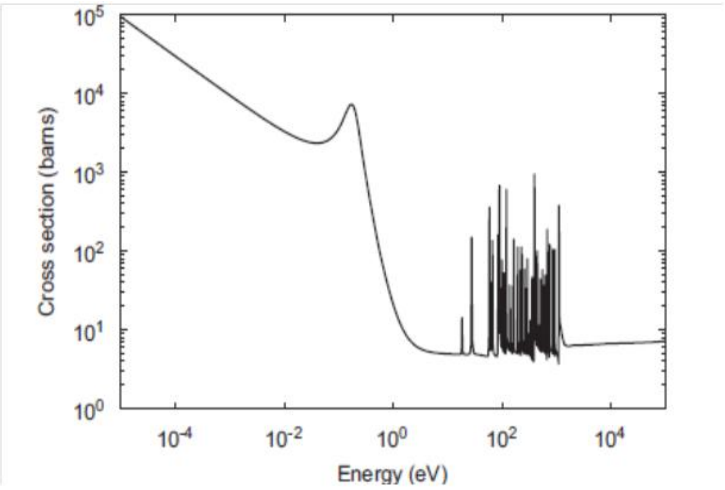

Figure 1: The Total Neutron Cross-Section for Natural Cadmium

With the growing demand for a more accurate cross-section determination, precise methods of flux measurements are required. A neutron flux may be measured in terms of reaction rate in material whose cross-section, σ, is known absolutely as a function of neutron energy [3], [4]. One of the standard methods is to measure the cadmium ratios in which foils are used that have appreciable cross-section in the thermal and epithermal regions.

A minimum of 10^9 n/cm^2 s neutron flux is required for activation analysis [5]; [6]; [7]; [8]. Duration of irradiation varies with application. Neutrons emitted during the fission of

U-235 have energies in the range 0–25 MeV and are far too energetic; they would mostly induce fission reaction that would rather complicate our work. Therefore, the work is concerned with the evaluation of cadmium thickness that best filters out thermal neutrons optimally in the characterization of gold from gold matrix.

2. MATERIALS AND METHOD

Reconnaissance of locations suspected to have gold deposits were undertaken before the actual collection of samples. In total, fourteen samples were collected at places where local gold mining were been undertaken. The samples were then pulverized, homogenized and dried, each separately to avoid contamination. Of these fourteen samples, one (sample N) was chosen randomly from which fourteen samples were made.

Cylindrical cadmium shields of 0.5, 1.0 and 1.5mm were fabricated. Thereafter, a sample – in cylindrical cadmium shield – was exposed to full neutron flux of the reactor for a pre-determined

irradiation time (1, 2, 10 and 30minutes), then analyzed with HPGe detector which initially was calibrated for energy and efficiency using Co-60 and Cs-137.

2.1 Irradiation of Standards

Two SRMs [IAEA-soil-7 and Single Element (gold) standard foil (0.01396g)] were used for quality control and validation. Their irradiations and analyses were done under same experimental conditions (shielded in cadmium and two minutes exposure period) and the following results were obtained.

Table 1: Elements Concentrations (Ppm) in Selected Reference Materials using Epithermal Gamma-Ray Spectrometry

	IAEA-Soil-7		Gold Foil (single element standard)	
Analyte	Reported value	This work	Reported value	This work
Antimony	1.7	1.66±1.5%	-	-
Arsenic	13.4	13.12±1.5%	-	-
Gold	-	BDL	0.01396	0.01365±2.5%
Mercury	0.04	0.0406±2.0%	_	_

BDL: Below detection limit.

3. RESULTS AND DISCUSSION

The gamma spectra obtained for a 0.5mm cadmium thickness and a minute irradiation revealed that analyte of interest (gold) was not significantly activated and that the activities of elements that usually increases gold detection limit was significantly reduced. But at two minutes irradiation and same thickness, the energy peak of gold was clearly observed as depicted in figure 2. At ten minutes the gamma spectrum that resulted was not any different from figure 2, but the activities of the interfering elements became significant. Another observation was that the cadmium material became unwieldy. It was significantly radiative. At thirty minutes irradiation, matrix elements that do interfere with gold irradiation were considerable from the Compton continuum increase in the spectrum.

The second arrangement: cadmium of 1.0mm with different irradiation times revealed that only at two minutes irradiation was the optimal desired activation attained in the desired analyte. In this arrangement, least interference was achieved. Figure 3 illustrate the gamma spectrum of this arrangement depicting energypeak of gold much clearer when compared with figure 2.

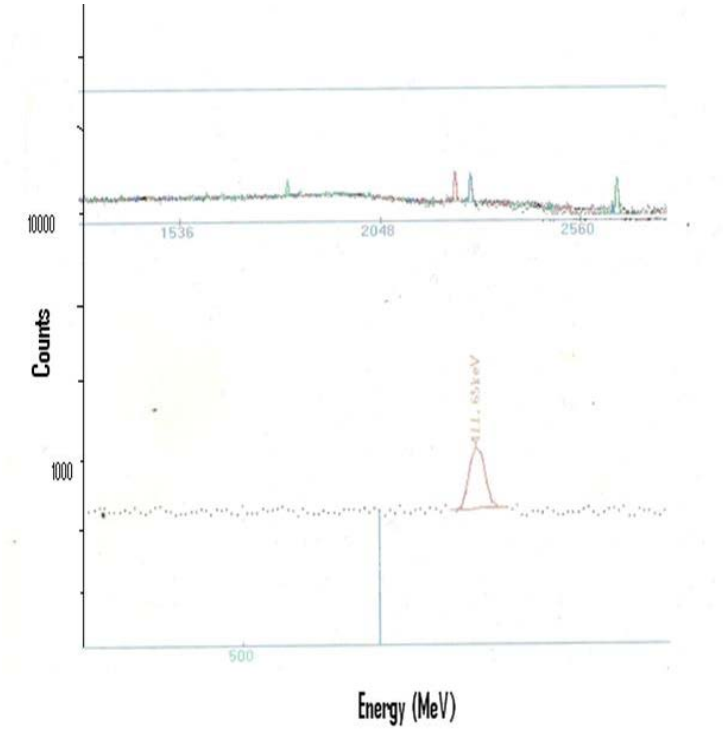

Figure 2: Gamma ray spectrum depicting energypeak of gold

Sub-arrangements within the second arrangement did yield results that were not as good as figure 2. In thirty minutes irradiation of this second arrangement, cadmium became so radiative that analysis was suspended until hazard to handling was within acceptable limit before samples could be retrieved from cadmium shield. Within this time frame, activity of the desired analyte fizzled out.

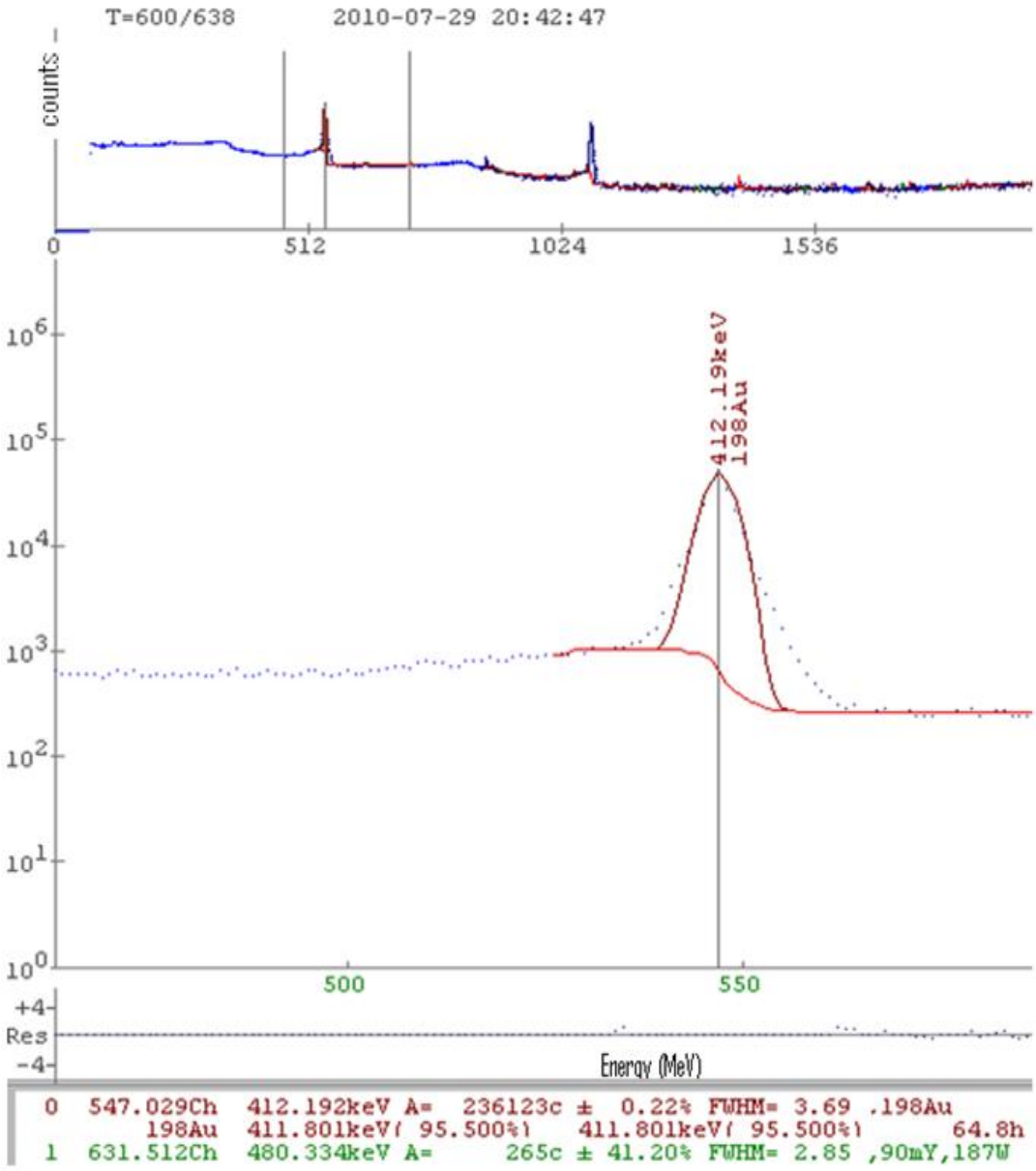

Figure 3: Gamma Energy Spectrum of Second Arrangement

The third setup: 1.5mm cadmium shield at different irradiation times was undertaken and the results showed that either the desired analyte was under-activated or cadmium became unwieldy. Nothing meaningful was attained here, but we suggest that further research be conducted on this setup.

The success in the second setup informed its application to the fourteen samples and the result obtained is shown in table 2.

Table 2: Element Concentrations (in PPM, Unless Otherwise Indicated) Obtained in analyses of Gold Ores Samples

Sample	Elements concentration							
	Au,	Mg, %	Al, %	Ca, %	Ti, %	V	Mn	Dy
Sample A	0.90±50%	0.54±0.03	2.00±0.05	BDL	BDL	4.3±1.2	3.0±0.1	BDL
Sample B	0.45±42%	0.17±0.02	1.20±0.04	BDL	BDL	BDL	0.6±0.1	BDL
Sample C	BDL	0.14±0.02	1.03±0.03	BDL	BDL	14.3±1.8	186±03	BDL
Sample D	345.6±1.5%	0.42±0.03	0.87±0.03	0.27±0.05	BDL	26.4±2.6	163±03	BDL
Sample E	7.99±8.3%	0.27±0.02	1.06±0.03	BDL	0.13±0.03	7.0±01	4.3±0.2	BDL
Sample G	487.6±1.4%	0.88±0.02	0..41±0.02	BDL	14.04±3.5	68.0±04	306±05	BDL
Sample I	BDL	0.70±0.04	2.00±0.05	BDL	BDL	BDL	2.3±0.1	BDL
Sample J	15.4±1.7%	0.28±0.03	3.10±0.1	BDL	BDL	36±04	117±02	BDL
Sample K	208.9±2.1%	BDL	BDL	BDL	9.70±1.3	BDL	380±06	BDL
Sample L	BDL	0.17±0.02	1.26±0.03	BDL	BDL	13±1.4	156±03	BDL
Sample M	3.8±18.2%	1.0±0.10	39.3±5.5	BDL	BDL	BDL	5.0±0.2	BDL
Sample N	473.8±1.5%	0.41±0.04	1.62±0.05	BDL	19.4±0.7	94±04	296±04	BDL
Sample P	543.9±1.5%	0.14±0.03	0.52±0.02	BDL	23.4±0.8	95±04	372±06	BDL
Sample Q	680±1.1%	BDL	BDL	BDL	BDL	BDL	322±05	BDL

As seen in the table, quite a number of the elements were indicated to be below detection limit. This is because Mg, Al, Ca, Ti, V, Mn, and Dy have Q_0 = 0.6, 0.7, 0.5, 0.7, 0.6, 1.1, and 2.8 respectively.

A careful look at these figures indicates that all these elements are not good candidates for ENAA as earlier stipulated, and so all the elements in table 2 but for Au may not reflect their true concentrations since the activating neutrons are of epicadimium The epicadmium neutrons flux density is typically only about one-tenth that of the thermal neutron flux in irradiation positions used for NAA [9].

Sample Q, posted a concentration of Au = 680 ± 1.1% which when compared with the concentration of other elements in that column, shows that gold was very high in that sample. This may likely be the reason for the high concentration of mining activities in that area.

4. CONCLUSIONS

The result of the study reveals that miners desiring a fast characterization of gold matrix using INAA should use epithermal neutrons in the analyses. Where cadmium shield is required, cadmium of 1.0mm thickness is observed to be more efficacious.

ACKNOWLEDGMENT

The authors wish to thank Prof. S Jonah of Centre for Energy Research and Training, Zaria for timely intervention that made this work possible and a success. We also thank Engineer Rufai of same Institute.

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