A Preliminary Study on Detecting Fake Gold Bars Using Prompt Gamma Activation Analysis: Simulation of Neutron Transmission in Gold Bar

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1. Introduction

Gold bars have been used as the currency by the following reasons. It is easily transportable because it has high value to weight ratio, also it is fungible with a low margin between the prices to buy and sell. Under the gold bullion standard, it guaranteed the government would redeem any amount of currency for its value in gold. After the gold bullion standard ended, gold bars have been the target for investment as ever. But it is well known that fake gold bar exist in the gold market. This cannot be identified easily without performing a testing as it has the same appearance as the pure gold bar. In order to avoid the trading of fake gold bar in the market, they should be monitored thoroughly.

The purpose of this study is to develop fake gold bar detecting method by using Prompt-gamma activation analysis (PGAA) facility at the Korea Atomic Energy Research Institute (KAERI). PGAA is an established nuclear analytical technique for non-destructive determination of elemental and isotopic compositions. For a preliminary study on detecting fake gold bar, Monte Carlo simulation of neutron transmission in gold bar was conducted and the possibility for detecting fake gold bar was confirmed.

2. Materials & Methods

2.1 Neutron sources from HANARO reactor

The HANARO research reactor at the Korea Atomic Energy Research Institute (KAERI) has been operated at 30 MWth since its first critical in 1995. The HANARO reactor has provide thermal neutron beams with high flux (5×10^{14}) for characterizing the composition and structure of a target substance. To enhance the utilization capacity of the HANARO reactor, a cold neutron research facility has been developed since 2003 and the Cold Neutron Activation Station (CONAS) has been constructed for various applications of cold neutrons [1]. The CONAS consists of two neutron activation instruments, one of them is Cold Neutron Prompt Gamma Activation Analysis (CN-PGAA) facility.

2.2 Physical properties of target substances

There are different sizes of gold bar in the world. The largest gold bar of Korea Gold Exchange measures about $60 \times 110 \times 8$ mm^3, its weight is 1000g. The Minimum purity of standard gold bar is 99.5% gold. But a fake gold bar is commonly made by filling inside of the bar with other substances, particularly tungsten that has the density (19.3 g/cm^3) nearly the same as gold (19.25 g/cm^3) but its price is cheaper [2]. In order to assume the case of fake gold bar, tungsten was selected as a representative fake candidate and its physical properties compared with those of gold in Table I.

Table I: Physical properties of target substances.

	Gold (Au)	**Tungsten (W)**
Atomic number	79	74
Molar mass (g/mole)	196.97	183.84
Density (g/cm^3)	19.3	19.25
Total micro cross section for thermal neutron (barn)	98.65	18.21

2.3 Monte Carlo simulation

The incident neutrons at the internal layer in the pure and fake gold bar were calculated by using the Monte Carlo N-particle extended code package MCNPX, which enables one to simulate transport of neutrons, photons and electrons in medium and to define three dimensional geometries in an arbitrary way [3]. The fake gold bar was assume that 6 mm-thick tungsten bar was plated with 1mm-thick gold. The thermal and cold neutron beams from HANARO reactor were adopted as a source in simulation. Especially the source data for cold neutron was made with the energy distributions of cold neutron in CONAS simulated with Monte Carlo Simulation of Triple-Axis Spectrometer (McStas) by Hoang et al. [4].

The simple geometry of neutron irradiation system in MCNPX simulation was modeled after the CONAS CN-PGAA facility. The neutron beam is transported to the analytical sample inside the sample mounting box by a tube. The beam tube is used to collimate neutrons from the end of the cold neutron guide line. The sample mounting box measures $20 \times 20 \times 20$ cm^3, suitable for accommodating gold bar. A schematic of the neutron irradiation system and simulated neutron tracks by using MCNPX design tool: Visual EditorX_24E is showed in fig. 1. The Visual Editor (version_24E) allows the user to easily set up the view of MCNPX geometry and particle tracks [5].

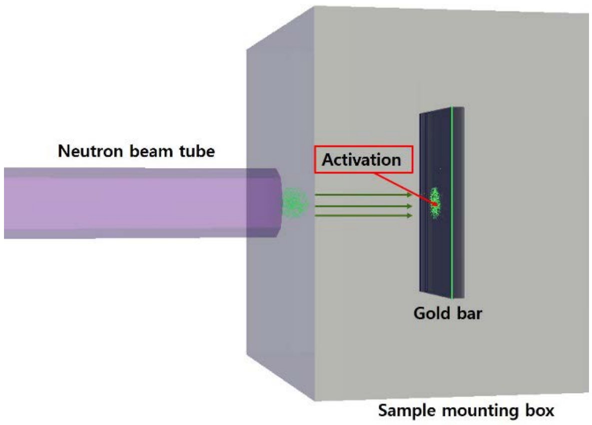

Fig. 1. A schematic of the neutron irradiation system modeled after the CONAS CN-PGAA facility and the simulated neutron tracks by using MCNPX design tool: Visual EditorX_24E.

All calculations were carried out using 10^7 particle histories resulting in target relative error R less than 1 %. Relative error R is usually used as a parameter to stop the run, R less than 1 % signify the calculation is reliable.

3. Results and Discussion

3.1 Mean free path of neutron for gold and tungsten.

The mean free path of neutron for gold and tungsten obtained from MCNPX simulation are shown in table 2.

Table 2: Mean free path of neutrons for target substances

	Mfp of thermal neutron (mm)	Mfp of cold neutron (mm)
Gold	1.72	0.69
Tungsten	8.71	3.51

The mean free path of thermal neutron in tungsten is about five times bigger than that in gold. The mean free path of cold neutron also show a same tendency for the target substances. This result means that the neutrons interact with tungsten fewer than gold.

3.2 Transmission rate of neutron beams in pure and fake gold bar.

Transmission rates of thermal and cold neutron beams in pure and fake gold bar are shown in fig. 2(A) and 2(B). In the Y axis of the graph, F_0 and F(x) represent the number of incident neutrons at the surface and a depth of x in target, respectively. To the depth of 4 mm corresponding to half thickness of the pure gold bar, 10 percent of initial incident thermal neutrons can be penetrated. For the cold neutron, only 0.64 percent of initial number can be penetrated. But in the fake gold bar, 39 percent of thermal and 8 percent of cold neutron can be penetrated to the depth of 4 mm.

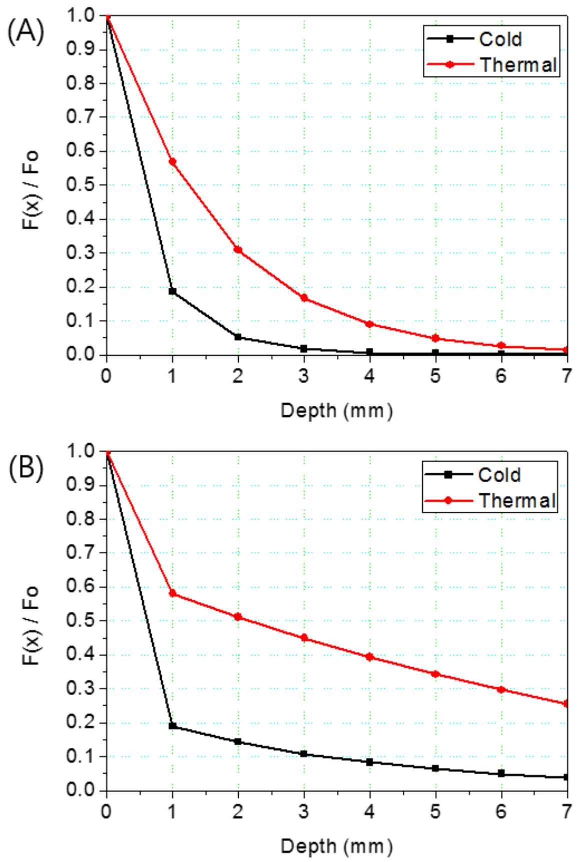

Fig. 2. Transmission rate of two energy neutron beams (cold, thermal) in (A) pure and (B) fake gold bar.

Although the transmissivity of cold neutrons are low comparing that of thermal neutrons, the slower neutrons are more apt to be absorbed in a target, and can increase the prompt gamma emission rate. Also the flux of both thermal and cold neutron beam is high enough to activate thick target. If the neutron beam is irradiated on the front and the reverse side of gold bar, all insides of it can be detected.

REFERENCES

[1] G. M. Sun, Development of HANARO Cold Neutron Activation Station, in: Transactions of the 13th International Conference on Modern Trends in Activation Analysis, Mars.13-18 2011, Texas, USA.
[2] I. Prasetiyo, I. Sihar, K. Agusta and I. Handayani, A Gold Bar Purity Testing Method Based on Vibration Characteristics, In Applied Mechanics and Materials, 771, pp. 223-226, 2015.
[3] D. B. Pelowitz, MCNPX User's Manual Version 2.7. 0–LA-CP-11-00438, Los Alamos National Laboratory, 2011.
[4] S. M. T. Hoang, G. M. Sun, J. H. Moon, Y. S. Chung and B. G. Park, Optimization of HANARO cold neutron induced prompt gamma activation analysis system by using Monte Carlo code, Journal of Radioanalytical and Nuclear Chemistry, 296(2), pp. 967-973, 2013.
[5] A. L. Schwarz, R. A. Schwarz and L. L. Carter, MCNP/MCNPX Visual Editor Computer Code Manual, 2008.