Fast Neutron Activation Analysis of gold by inelastic scattering, ^{197}Au(n,n'γ)^{197}Au^m, by means of Plasma Focus device

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Abstract The application of a Fast Neutron Activation Analysis (FNAA) technique on samples of pure gold, irradiated by a plasma focus of 7 kJ, has been investigated. The reaction was the inelastic scattering of neutrons, ^{197}Au(n,n'γ)^{197}Au^m. To avoid problems connected with peculiar features of the neutron emission from this kind of source, a preliminary standardisation of the method has been carried out. The results obtained have a practical interest in view of possible applications to the technology of extraction of minerals.

Key words activation • gold • neutron • plasma focus

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Introduction

The percentage of gold in gold-fields is determinant for its exploitation. Since it is economically convenient to process an ore sort till the amount of gold in the rock is about 1 ppm, an on-line knowledge of the quality and quantity of materials (relating to minerals extraction), allows to decide if the amount of gold in a sample justifies the extraction treatment.

Many elemental techniques can be used to determinate the total and absolute amount of different elements in materials, but nuclear techniques, like Neutron Activation Analysis (NAA), allow to have a fast and easy-to-detect response. The problems encountered, considering a nuclear technique for technological applications, are generally due to radiation protection, expert maintenance and costs of the neutron production devices, which are not easy to handle. On the contrary, a plasma focus (PF) is a relatively low price – easy handling source and it limits its radiation emission to the pinch phase (50–200 ns) without any radioactive impurity, even in case of an accident. Hence, the PF would be a very good choice and the construction of a portable device of PF type would enable to perform Fast Neutron Activation Analysis (FNAA) *in situ*.

Owing to its high cross section for thermal and fast neutrons, NAA of gold is a well-known and largely applied technique in the nuclear research field. Usually, using this method, the determination of the percentage of different elements in the sample is made through comparators, but, when this procedure is too difficult, as for a PF source, a different approach must be undertaken.

Fig. 1. Experimental apparatus.

Fig. 2. Cross sections of the ^{27}Al(n,γ), ^{27}Al(n,p), ^{27}Al(n,α), ^{27}Al(n,d), ^{28}Si(n,p), ^{28}Si(n,α), and ^{197}Au(n,n'γ) reactions.
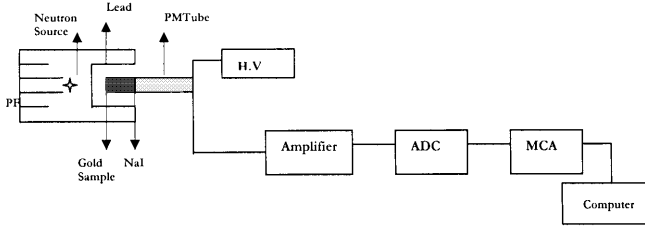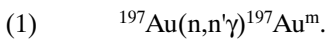
This article reports very preliminary measurements performed to find out the suitability of an easy method to detect the amount of gold in a sample using a PF of 7 kJ capacity as a neutron source.

Methods

The inelastic scattering reaction we used to detect the gold percentage in ore sorts was:

(1) ^{197}Au(n,n'γ)^{197}Au^m.

This reaction has a half-time $T_{1/2}$ = 7.8 s and a cross section for activation σ ≅ 1b (only 73.6% of activated nuclei give rise to a γ emission) at E_n = 2.45 MeV. E_n is the energy of the incoming neutron produced by a PF source, operating with pure deuterium (considering the neutron emission from a PF as monochromatic). The energy value of the emitted γ is: $E_γ$ = 279 keV. Fig. 2 shows the cross section variation for inelastic scattering and for some other reactions which can occur in a typical ore [1].

The decay detection has been performed with an NaI(Tl) scintillation crystal (efficiency ≅90%) connected to a MCA and a computer [2]. A gold sample was located just in front of the scintillator in order to detect the maximum number of photons (half of the total emission). The head of the detection system, as shown in Fig. 1, was covered by a cylinder made of lead to suppress X-rays of about 300 keV coming out from the PF device. This reaction has been chosen
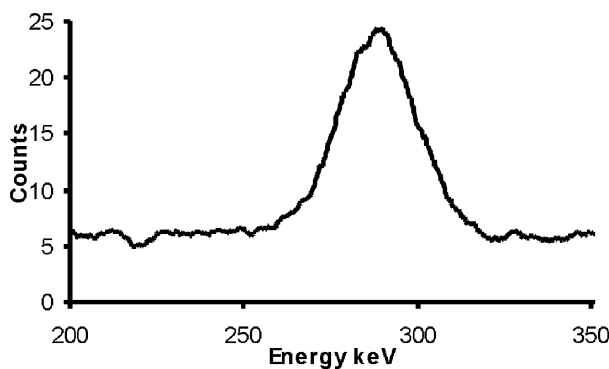
because of its high cross section as compared with other reactions which can occur with other elements in the samples at this neutron energy value (Fig. 2).

Results

The samples were thin targets made of pure gold (99.99%) of three different weights: 3.91 g (sample A), 1.43 g (sample B) and 0.6 g (sample C), respectively. Figs. 3, 4 and 5 show typical results obtained for different samples under different neutron irradiation. The measured γ emission was different even in the samples of the same weight. This was due to the different neutron production from different shots.

Discussion

In case of an isotropic and continuous flux, as NAA is usually performed [3], the knowledge of σ, φ, t_i and $T_{1/2}$ allows to make absolute calibrations through a comparator. This is a standard of known weight and composition to be irradiated simultaneously (for the same time and in the same flux) with the unknown sample. In this way, an amount of gold in the sample is easy determined through the relation:

(2) $W_x = W_s Y_x(γ)/Y_s(γ)$,

where: W_x – weight of gold in an unknown sample, W_s – weight of gold in the standard, $Y_x(γ)$ – γ emitted by the unknown sample, $Y_s(γ)$ – γ emitted by the standard.

Fig. 3. Spectrum obtained with a sample of 3.91 g of pure gold (sample A). Neutron production 3.7×10⁸.

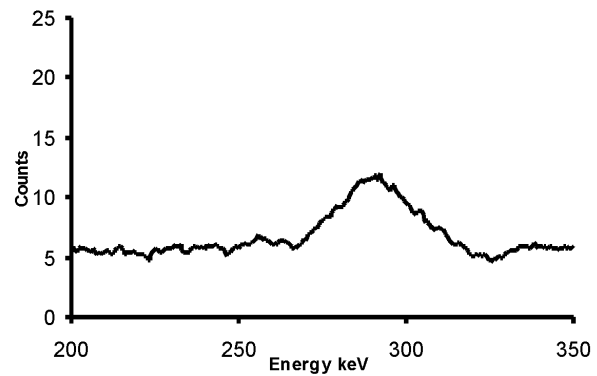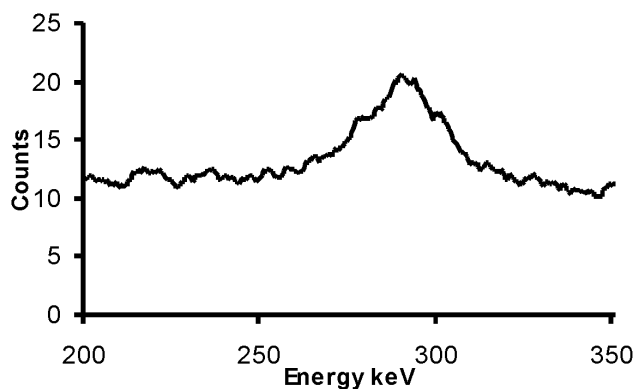Fig. 4. Spectrum obtained with a sample of 1.43 g of pure gold (sample B). Neutron production 3.2×10⁸.

Fig. 5. Spectrum obtained with a sample of 1.43 g of pure gold (sample B). Neutron production 5.5×10^8.

Fig. 6. Linear correlation between neutron production and γ detection.

Unfortunately, as already said, the neutron emission from a PF is neither constant nor isotropic. To avoid these problems a calibration of the equipment with samples of known weight has been carried out. In order to compare results for different samples under different fluxes, they must be referred to the same amount of gold, e.g. 1 g. After this reduction to the same weight, a linear dependence ($R^2 = 0.96$) between neutron production and γ detection per gram, $Y_g(\gamma)$, has been found, as shown in Fig. 6. The values of $Y_g(\gamma)$ are referred to the total yields of the source, $Y(n)$, which are the most direct experimental data. Besides, the exact flux impinging on the sample surface is not well known, owing to an unknown contribution due to scattered neutrons inside the discharge chamber.

In this way, it is possible to detect the amount of gold in a sample from the relation:

$$(3) \qquad W_x = Y_x(\gamma)/Y_g(\gamma),$$

where $Y_g(\gamma)$ is easily found from the diagram in Fig. 6, knowing the value of $Y(n)$.

Assuming a standard deviation for $Y_x(\gamma)$ equal to 10%, the minimum quantity of gold that can be detected, with a neutron emission of $Y(n) \cong 5 \times 10^8$ (the best for a PF of 7 kJ), is about 0.2 g.
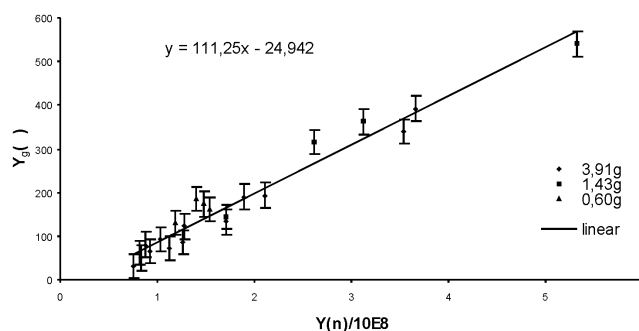
Conclusion

From preliminary measurements, performed on samples of pure gold, FNAA, using as neutron source a PF of 7 kJ, can detect, at the best, quantities of pure gold down to ~0.2 g, with a precision of about 10%. The ore samples of auriferous sand are usually of about 10 kg with a volume of about 10^4 cm^3 and the minimum content of gold to be detected is about 10^{-2} g. So, other measurements with more powerful PF sources and suitable detectors must be performed taking into account the characteristics of the real sample (for example the self-absorption). Nevertheless, from the first results, presented above, the use of a PF source for this type of application seems to be very promising.

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