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An internal standard for Fast Neutron Activation Analysis spectra obtained by means of Plasma Focus devices

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Abstract The behaviour of Pb activation peaks, which appear in an X-ray spectrum of Fast Neutron Activation Analysis (FNAA) performed by means of a Plasma Focus (PF) neutron source and an NaI scintillator counter, has been studied. The PF device generates neutron bursts of different intensities. To know the exact neutron flux illuminating a sample during PF discharges an external neutron counter is usually used. The nature and behaviour of the indicated peaks suggest that one could use one of them as an internal standard for neutron production measurement instead of an external counter. This technique allows more reliable and accurate determinations of the presence of various elements.

Key words gold • inelastic scattering • lead • mineral resources • NAA • plasma focus

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Introduction

In a recent paper [7] the use of a Plasma Focus (PF) neutron source, to detect gold percentage in ore sorts by mean of Fast Neutron Activation Analysis, has been reported. The $^{197}Au(n,n'\gamma)^{197}Au^{m}$ inelastic scattering reaction has been used to detect gold percentage in ore sorts.

This reaction has a half-time $T_{1/2}$ = 7.8 s and the cross section for activation is ~1 b at E_n = 2.45 MeV (only 73.6% of activated nuclei gives rise to γ emission). E_n is the energy value of the incoming neutron produced by a PF source operating with pure deuterium (considering the neutron emission from a PF as monochromatic). The energy of the emitted γ is: E_γ = 279 keV. Since ore sorts are metalliferous sands (SiO_2 containing Al and Ag) it is necessary to use a nuclear technique such as Fast Neutron Activation Analysis; the technique being highly selective [3] in relation to other reactions: $^{197}Au(n,\gamma)$, $^{27}Al(n,\gamma)$, $^{27}Al(n,p)$, $^{27}Al(n,\alpha)$, $^{27}Al(n,d)$, $^{28}Si(n,p)$, $^{28}Si(n,\alpha)$, it is possible to have high energy photons which can overcome a sand layer and be detected with a cheap and rugged detector such as NaI(Tl). Using a PF as a neutron source, thanks to its nearly isotropic emission, it is possible to irradiate huge amounts of gold sands and to use large area detectors in order to increase their efficiency. During measurements of gold samples irradiated with fast neutrons (2.45 MeV) in addition to the 279 keV photon produced by $^{197}Au(n,n'\gamma)^{197}Au^{m}$, there were observed four other peaks, of different energies and with different half-lives, appearing even in the absence of gold samples. These peaks have energies very different from gold's photon energy (and their activity is very low) and did not create any problems for gold activation measurements. The first two peaks, observed at lower energies in Fig. 1, have not been prop-

erly detected. The last two peaks, observed at higher energies, seem to be due to Pb inelastic scattering reaction $^{207}Pb(n,n'\gamma)^{207}Pb^{m}$ within the shield of the photon detector. Although Compton scattering, due to photons belonging to these peaks, can affect the activation detection, this contribution is negligible.

The main purpose of this work was to determine and to use (if possible) the peaks appearing at higher energies within gold-FNAA spectra as internal standard in substitution or in addition to conventional neutron counters [1, 4].

Experimental set-up and results

To determine peak energies a standard configuration has been used. The calibration was performed with radioactive sources of ^{241}Am, ^{133}Ba and ^{137}Cs, as reported in [7]. Decay detection has been carried out by means of an NaI(Tl) scintillation crystal connected to a Multichannel Analyser (MCA) and recorded by a personal computer. The gold sample was located just in front of the scintillator, to detect the maximum number of photons (half of the total emission). The samples were thin targets made of pure gold (99.99%). The head of the detection system was covered with a cylinder made of lead in order to suppress soft and hard X-rays coming out from PF shots. In Fig. 1 is shown a typical result of a gold activation measurement. This spectrum has shown (in addition to the peak of gold at 279 keV) four peaks which appeared in the monitor of the detection chain when the gold sample were absent. The energies of those peaks, given in Table 1, correspond to the well-known energies of photons emitted from neutron activation of Pb [6].

To confirm the origin of the peaks many measurements of their energies and half-lives have been carried out. A block diagram of the equipment, which was a simple modification of the apparatus previously used for gold percentage determination [7], is shown in Fig. 2. In this system an amplified outcoming signal is processed with a Single Channel Analyser. The Single Channel Analyser allows selecting a signal through its voltage amplitude and gives back a TTL (Transistor Transistor Logic) signal for each signal, which lies in the chosen voltage window. The TTL signals are then processed in a Multichannel Scaler (MCS), which sums the signals over a fixed period of time. This configuration allows to drive both stepping (to measure time inside a channel) and waiting (time interval between one channel and the next one) via an external BNC connector (pulse shape generator and trigger). The MCS is usually connected with a Personal Computer to store and process spectra.

Table 1. Energy peaks.

	Energy (keV)
Peak 1	25
Peak 2	75
Peak 3	569
Peak 4	1063

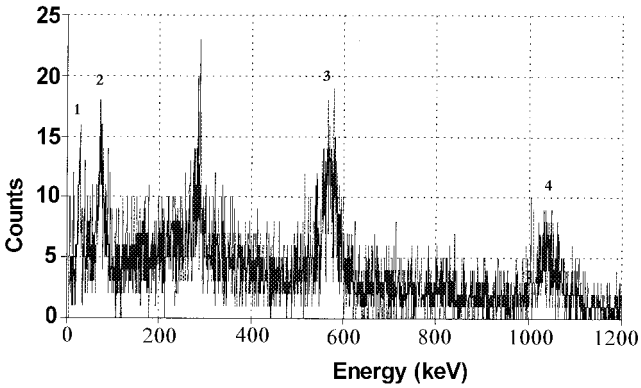

Fig. 1. Spectrum of FNAA of gold, exhibiting the four additional peaks. Neutron production ($Y_n = 9.8\times10^8$), was measured by means of the internal standard.

Since Y_n (neutron yield from a PF discharge) is neither constant nor predictable, several counting times have been used to determine the $^{207}Pb^{m}$ nucleide half-live. For example, the 569 keV peak was measured for a different period varying from 10 ms to 1 s. In order to minimise counting errors, the minimum waiting time equal to 10 μs has been chosen. Fig. 3 represents a decay profile for the 569 keV peak. The experimental data have been fitted with a mathematical program in order to determinate peak half-lives. The results of fitting and their standard deviations are presented in Table 2. Comparing these results with the literature tables [2, 5] on nuclei decay one can conclude [1, 4, 6] that the observed peaks come from the inelastic scattering

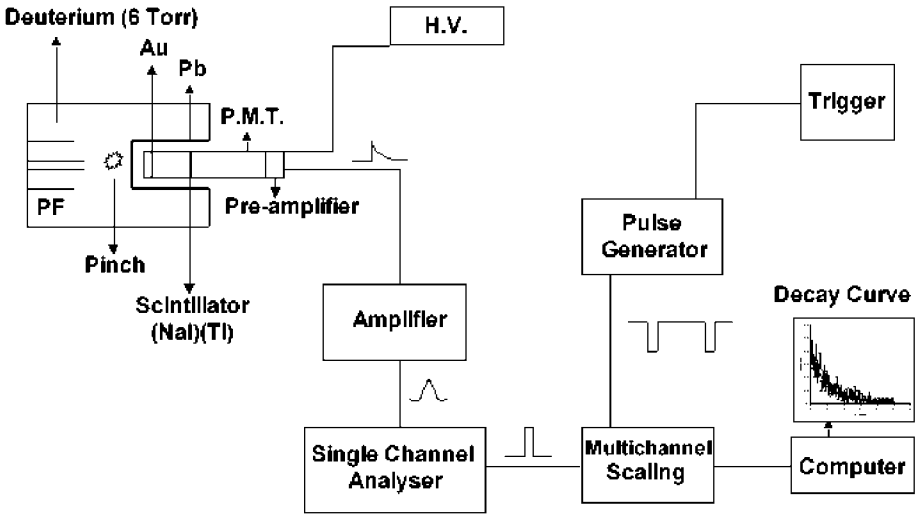

Fig. 2. Determination of peak half-lives.

Table 2. Fitting curve results.

	$T_{1/2}$	σ_T
1063 keV	0.95	±0.04
	0.81	±0.03
1063 keV	0.85	±0.01
	0.81	±0.02

Table 3. Levels for ^{207}Pb: ^{207}Pb IT decay.

E_{level}	E_γ	J_π	$T_{1/2}$
0		1/2-	
569.7	569.702	5/2-	
1633.4	1036.662	13/2+	0.806

reaction ^{207}Pb(n,n'γ)^{207}Pb^m, which gives rise to an isomeric transition (IT) decay. In Table 3 a weighted average value of $T_{1/2}$ is shown [2, 5].

As the same quantity of Pb gives rise to a higher peak at 569 keV, than at 1063 keV, it seems more convenient to refer neutron production to the number of 569 keV photons.

In order to use the Pb activation as an internal standard, one ought to find a linear relation between the 569 keV photon intensity and the amount of gold in a sample, measured through a 279 keV photon intensity. In Fig. 4 the corresponding correlation (coefficient r = 0.99) is shown. On the x-axis 569 keV photon intensity is plotted, while on the y-axis – 279 keV intensity, as measured with the same amount of Pb and Au (1 g) for each experiment. An error in the neutron counting for this method was ≈ 10%, i.e. about one half of the conventional GM silver activated counter error (≈20%).

Using the method described it is possible to determine, with an 569 keV photon yield of ≈ 3000 counts (equivalent to 1.1×10^9 neutrons), an amount of pure gold equal to 0.12 g with an error of about 10%.

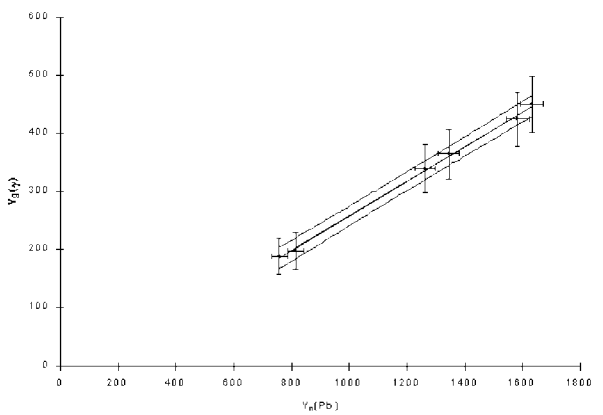

Fig. 4. Linear correlation (r = 0.99) between 569 keV photons from ^{207}Pb(n,n'γ)^{207}Pb^m and 279 keV photons intensity from ^{197}Au(n,n'γ)197Au^m.

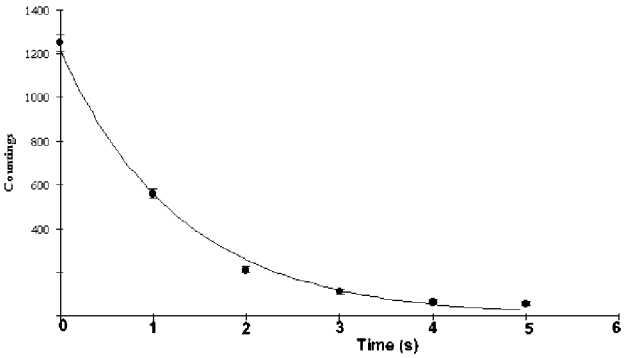

Fig. 3. Exponential decay of the 569 keV peak, $T_{1/2}$ = 0.81±0.02 s; counting time = 0.2 s; stop time = 10 μs; neutron production $Y_n = 1.1\times10^9$.

Conclusion

The nature and behaviour of the peaks, which appear in the spectrum of FNAA of gold, as performed with the PF neutron source has been investigated, within the range 0–1200 keV, particularly for the peaks observed at 569 and 1063 keV. These two peaks, which are present also in the absence of the gold sample, come from neutron activation of the lead shield of the NaI counter and can be used as an internal standard to determine PF neutron emission. With this technique, the error of the determination of the neutron yield is considerably lower than 20% of the conventional Geiger-Muller silver activated neutron counters. Therefore, it is possible to observe a quite low percentage of gold in a sample. The usefulness of the method described is still more evident in the case of a repetitive PF source, since the very short Pb decay allows the neutron yield to be detected shot-to-shot.

References

1. Brzosko JS (1983) Investigation of high-energy deuterons in a dense plasma focus device by means of neutron emitted in the ^{7}Li+D process. Nucl Technol, Fusion 5:209–223
2. Campbell EC (1956) Rapid ion-exchangee techniques for radiochemical separations. J Inorg Nucl Chem 3:233–238
3. Clayton CG, Wormald MR, Schweizer JS (1990) Nuclear method for on-line analysis of metalliferous and non-metalliferous minerals. In: Proc Nuclear Techniques in the Exploration and Exploitation of Energy and Mineral Resources. IAEA, Vienna, pp 107–134
4. Ruby L, Rechen JB (1962) A fast-neutron activation detector for 14 MeV pulsed neutron source. Nucl Instrum Meth 15:74–76
5. Salaita GN (1973) Isomeric cross section for (n,2n) reactions in Tl, Pb, and Bi, at 14.8 MeV. J Inorg Nucl Chem 35:2139–2143
6. Spencer LE, Jacobs EL (1964) The lead activation technique for high energy neutron measurement. IEEE Trans Nucl Sci, NS 12:407–414
7. Verri G, Mezzetti F, Da Re A, Bortolotti A, Rapezzi L, Gribkov VA (2000) Fast neutron activation analysis of gold by inelastic scattering, ^{197}Au(n,n'γ)^{197}Au^m, by means of plasma focus device. Nukleonika 45;3:189–191