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IDENTIFICATION AND ESTIMATION OF GOLD (AU^{197}) PRESENT IN A FORMAT BY NEUTRON ACTIVATION AND GAMMA RAY SPECTROSCOPY*

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A method is given for identification of gold, present in a format in micro quantities , by Neutron activation and gamma ray spectroscopy, employing a NaI (Tl) detector system. Gamma radiation spectrum of the activated element displays characteristic photo peaks at specific energies (E) and definite half life ($T_{1/2}$). The determined values of E and $T_{1/2}$ can be used to ascertain the presence of gold in the format. The weight of the element in the format has been estimated with the help of data obtained in an ancilliary experiment, performed simultaneously. The weight is found to be $(11.1 \pm 0.2)\mu$ g. This method can be used for prospecting of gold and other elements in unknown samples.

INTRODUCTION

The presence of gold (Au^{197}) in a format can be ascertained by obtaining gamma ray spectrum of the element, activated by irradiation of the format with neutrons in the core of a research reactor, with a NaI (Tl) detector system and by comparing this spectrum with the standard spectrum produced by the characteristic gamma rays of the radioactive Au^{198} [1]. The most prominent gamma peak in the spectrum is chosen. The energy for this gamma peak and half – life of the radionuclide are determined and knowledge of these two characteristics is sufficient to identify the element unambiguously [2]. The exact content of the element in the format is estimated from the data on the activity of the element in the format and the activity of a standard sample of gold, irradiated alongwith the format under same conditions.

EXPERIMENTAL SET-UP

A block diagram of the experimental setup is shown in Fig. 1. A = 3" x 3" NaI (Tl) Detector: B = Preamplifier; C = E.H.T.; D = Amplifier. E = Multichannel Analyzer (MCA); F = Printer.

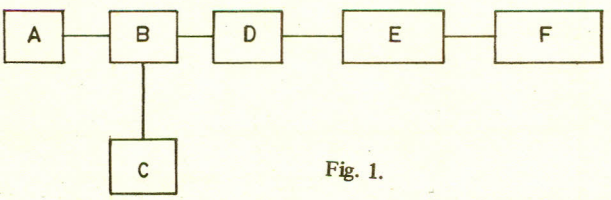

Fig. 1.

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The Georigia Tech. Research Reactor (GTRR) TMC Unit, 400 channels, Model 404, Printer Model 500 P, were made by Technical Measurement Corporation, North Haven Conn., U.S.A.

FORMAT, STANDARD SAMPLE AND NEUTRON ACTIVATION

The element (Au^{197}) was dissolved in (75% HCl + 25% HNO_3) and contained in a sealed polythene cylinder of dia~0.9 cm inner and 1.15 cm, outer, total height ~ 2.54 cm, about half-filled with the gold solution. The total weight of the format was ~ 1 g. The standard sample of gold was an Al – Au wire, total weight 8 mg, containing 0.1 % Au^{197} i.e. weight of Au^{197} was 8μ g. The format and the Al – Au, encolosed in a plastic bag, were irradiated with neutrons in the GTRR core (Rabbit H – 15) for 30 sec. in the available thermal neutron flux~10^{13} n/cm^2 – sec. The time, t_w, after the activation was kept by running a (Minerva) clock continuously.

RESULTS, GAMMA RAY SEPCTROSCOPY

Before taking the gamma spectrum of the activated format, the entire experimental set-up and the multichannel analyzer was calibrated with standard sources Na^{22}, Cs^{137} and Co^{60} which emit gamma rays of energy (MeV) 0.51; 0.67; 1.17 and 1.33, respectively. Calibration curve for the detector system is shown in Fig. 2.

The entire spectrum of the format, taken about an hour after activation, is shown in Fig. 3.

The peak energies have been found on the basis of the calibration curve and are listed in Table. 1

Table 1. Energies of gamma peaks

Gamma peak	Channel No.	Energy (E) (Mev)
I	16	(0.42 ± 0.02)
II	66	(1.30 ± 0.02)
III	87	(1.68 ± 0.04)
IV	118	(2.27 ± 0.06)

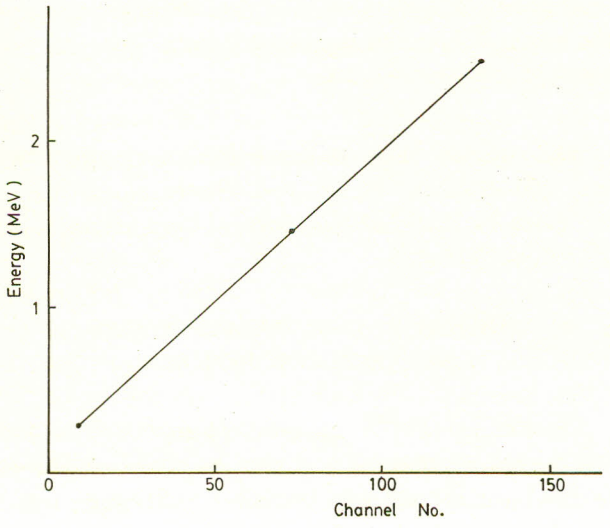

Fig. 2. NaI (TI) calibration curve.

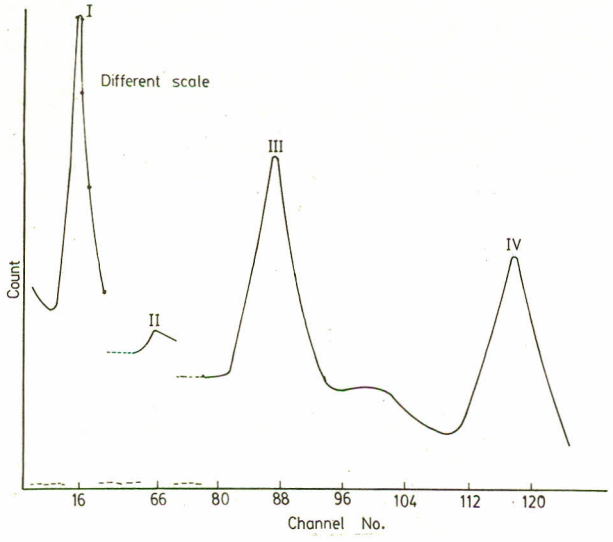

Fig. 3. NaI (TI) spectrum of format 1.3 hr after activation.

The decay curves for all the gamma peaks have been plotted and are shown in Figs. 4,5 and the values of half – lives ($T_{1/2}$) for these gamma activities have been found and are given in Table 2.

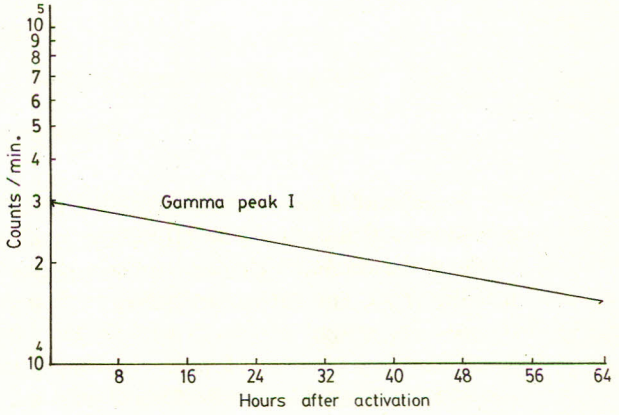

Fig. 4. Decay curve.

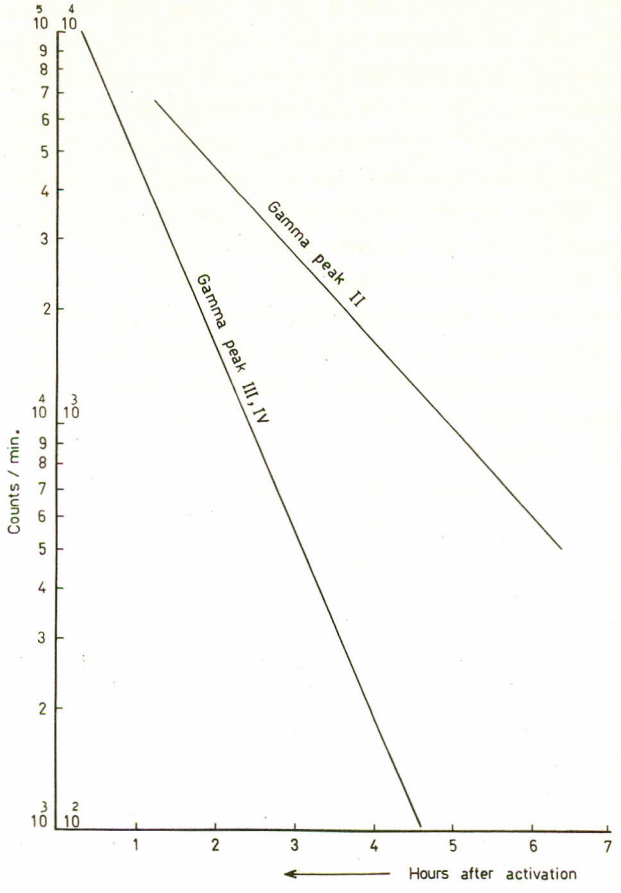

Fig. 5. Decay curves.

Table 2. Values of half-lives for gamma peaks.

Gamma peak	Half – life ($T_{½}$)
I	(2.76 ± 0.13) d.
II	(1 – 2) hr.
III, IV	(38 ± 1.00) min

The activities A_c^s and A^{iw} of the format and the wire respectively were recorded at noted values of time t_w and Thevalues of the activities A_c^s and A_c^w, corrected for the loss of time after activation were determined in accordance with the formula given in Appendix–A.

CONCLUSIONS AND DISCUSSION

The radionuclides emitting gamma peaks (Fig. 2) were identified by comparing the determined values of Eγ and $T_{½}$ and keeping in view the (n, γ) mode of their formation with those of the standard gamma ray cmitters, listed in order of increasing energy of gamma rays, their half lives, some modes of their formation, the values of σ etc. [2]. It is concluded that the radionuclide, emitting the gamma peak I is Au^{198} and the presence of Au^{197} in the format is confirmed. The radionuclides, emitting gamma peaks III, IV and II are Cl^{38} and A^{41}_r, respectively.

The presence of the radionuclide Cl^{38}, in the activated format, is explained by the fact that Au^{197} is dissolved in aqua regia which containes 75% HCl and the stable Cl^{37} gets activated when the format is irradiated with neurtons in the reactor core. The presence of the radionuclide A^{41}_r, in the activated format can be explained as due to the presence of either A^{40}_r as inert gas or some air left in the half – filled format container or both. The value of σ for A^{40}_r is nearly same as that for Cl_{37}. [2]

The determined value of $T_{½}$ for A^{41}_r is lower than the actual value. The reason for this seems to be that the nearest gamma peak of the shorter-lived Cl^{38} is contributing to the activity of the A^{41}_r peak thus bringing down the $T_{½}$ of the latter. Some more readings of the activity of gamma peak II (Fig. 4) could have improved the value of $T_{½}$ for A^{41}_r. however, there is no nuclide with Eγ ~ 1.2 MeV and $T_{½}$ (1 – 2) hr. except A^{41}_r. [2] On substituting the values of A_c^w and A_c^s in the formula given in Appendix A, the weight, W_s, of Au^{197}, present in the format is found to be (11.1 ± 0.2) μ g. In deriving the formula for W_s, the efficiency of the detector system has been assumed to be the same for the activated format and the Al – Au wire. Considering the dimensions of these gamma sources, the NaI (Tl) detector, the almost fixed source detector geometry and the nebligible attenuation of gamma rays within the activated format, the assumption seems to be justified.

In conclusion it is appropriate to say that the neutron activation and gamma ray spectroscopy provide a reliable, quick and perhaps the only method for an unambiguous identification and reasonabley accurate estimation of very minute quantities of an element like gold present in a format.

An unknown sample, like the natural ore, may contain a mixture of elements like Ag, Cu, Fe, etc. Such a sample can be analysed quantitatively by this method. Some of the radionuclides that can be formed by neutron activation of such an unknown sample, are listed in Table 3 alongwith the energies of the gamma rays emitted by them, their half lives, the values of σ etc [3]. It is evident that the energies of these photo peaks are such that these peaks can be resolved by the NaI (Tl) detector system.

APPENDIX A

Formula Used for Eximation of Gold in Format. When an element in a format is irradiated with neutrons, its nuclei may absorb neutrons to form an unstable isotope which is gamma-active and decays with definite half life, $T_{½}$, and energy, Eγ, of the radiations emitted. Such a nuclear reaction is called a (n, γ) reaction. The measured activity, A_c^s, of the element, at time t_w after activation, is given by [3].

$$A_c^{'s} = N_s \sigma \epsilon \phi [(1 - e^{-\lambda t_i}) e^{-\lambda t_w} \quad (1)$$

If a standard sample of gold is also irradiated with neutrons under the same conditins (ϕ, t_i) and counted on the same experimental set-up then the eq. (1) applies to the activity $A_c^{'w}$ of the standard sample and the factor $\gamma \epsilon \phi [(1 - e^{-\lambda t_i})$ can be eliminated getting

$$N_s = \frac{A_c^{'s} \times N_w}{A_c^w} \quad (2)$$

N_w pertains to the standard sample and A_c^s, A_c^w are the corresponding activities, corrected for the loss of time after activation, i.e.

$$A_c^{'s} = A_c^s \times e^{\lambda t_w}$$

Table 3

Element	Radionuclide produced	Gamma ray energy MeV	Half-life	δ (barns)
Ag^{107}	Ag^{108}	0.43, 0.62	2.3 min	30
Ag^{109}	$Ag^{110\ m}$	0.66, 0.89	25.5 d	2.8
Cu^{63}	Cu^{64}	1.34	12.8 hr.	4.4
Cu^{65}	Cu^{66}	1.04	5.1 min.	2.2
Fe^{58}	Fe^{59}	1.1, 1.2	45 d	0.9
Au^{197}	Au^{198}	0.41	2.7 d	98

and the efficiency, ϵ, of the detector system is assumed to be same for the two gamma sources.

The weight (gm), W_S, of Au^{197}, present in the format, is given by

$$W_S = \frac{N_S \times 197}{A} \qquad (3)$$

A being the Avogardo's number.
From equations (2) and (3) therefore

$$W_S = 197 \frac{(A_C^S)}{A_C^W} \frac{(N_W)}{A} \qquad (4)$$

The weight of Au^{197} in the standard sample is 8 μg so that, with the help of eq. (3), the required formula, for W_S, takes the form:

$$W_S\ (\mu g) = 8 \frac{(A_C^S)}{A_C^W} \qquad (5)$$

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2. D. N. Slater, Gamma Rays of Radionuclides in Order of Increasing Energy (1962).
3. U. S. Department of Health, Education and Welfare, Radiological Health (1960).