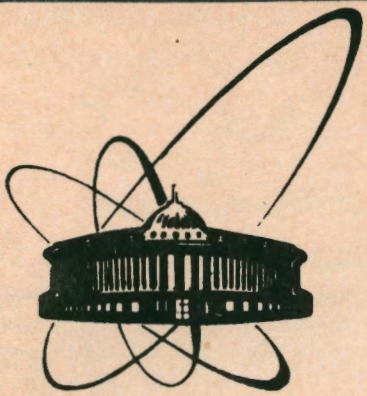

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TRACK RADIOGRAPHY OF HEAVY ELEMENTS IN MINERALS

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1. INTRODUCTION

The problem of low concentration measurements of heavy elements (Pt-Pb) in minerals is connected with searching for a new ore deposits. In many cases it is necessary to measure not only the average contents of the element in a sample, but to determine its spatial distribution in mineral with spatial resolution of about 10 μm.

For example, in one of deposits of Middle Asia in carbon rock the high level of Pt concentration was found out. It exceeded the background level of concentration of about 10^2-10^3 times. However, the next accurate mineralogy analysis did not confirm the presence of nugget Pt, which is usually formed at such levels of concentration.

The problem could be solved with the help of radiography method. It allows one to find out the spatial distribution of concentration in minerals. Moreover, after radiography, the spots with high platinum contents on the sample surface could be investigated supplementary with the help of electron microscopes and microanalyzers.

To solve such problems, the neutron - activation analysis is applied more often. For example, one uses the reaction ^{197}Au (η,γ) ^{198}Au [1] to measure low Au concentration in minerals. The sensitivity of this method can reach 10^{-8} g/g. However, the spatial resolution, which depends on the hard γ-ray spreading in the pattern and detector, is worse of 100 μm. Moreover, the background activation of many other elements, which are always present in the pattern, is 80% or even higher.

In this paper we shall consider the radiography of heavy elements in minerals by means of accelerated ions $^{12}_{6}C$ with registration of instant fission fragments and induced α-activity of products in reactions $^{A}_{Z}X(^{12}_{6}C, xn)\,^{A+12-x}_{Z-6}Y$.

The main advantages of f.f. and α-radiography have been shown in [2,3]. There are investigations, for example [4], which consider the radiography of concrete elements in minerals. However, for the radiography of wide spectrum of heavy elements in minerals it is necessary to find out the fragment yields for different bombardment ions, yields and half-life of induced

α-activity, relations between yields and energies of bombarding ions. Apparently, for every investigated element the optimal experimental conditions including the type of ion, its energy, exposure time and so on exist.

In our work we measured the yields of instant fission fragments and induced α-activity produced at the bombardments of Pt, Au, Pb targets by $^{12}_{6}C$ ions.

2. EXPERIMENTAL CONDITIONS

The exposure of the samples has been performed at the Laboratory of Nuclear Reactions, JINR in Dubna. The initial ion energy was 9.1 MeV/nucleon, integral ion flux was $3 \cdot 10^{12}$ cm^{-2}. To decrease the ion energy for some patterns, the Al foils were used. Accelerated ion beam bombarded the target from Pt, Au, Pb with natural isotope contents. The thicknesses of the targets exceeded the fragment ranges. On the bombardment surface of the target a thin (15 μm) mica nuclear track detector was placed to register the instant fission fragments. Ion beam vertical dimension was about 25 cm, and beam profile was rather homogeneous (Fig.1).

Induced α-activity was registered by CR-39 nuclear track detector. Exposure time was 1.5 hour and 144 hours to detect short-lived and long-lived components, respectively.

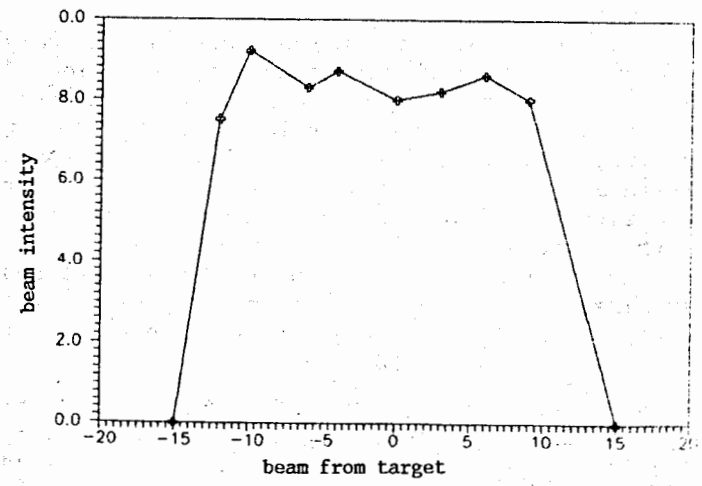

Fig.1. The ion beam profile on target surface.

Before etching, the mica detectors were being annealed at 450°C during 4 hours. Such a procedure eliminated the background tracks from recoil nuclei and compound nuclei tracks. To etch the detectors we used the well-known procedure[4,5].

3. EXPERIMENTAL RESULTS

In Fig.2 the dependencies of the backward fission fragment creation cross section σ_f of Pt, Au and Pb from the energy of bombardment ions are shown. In finding out the σ_f we took into account that effective target thickness which the fragments could left was 5 mg/cm^2. The curves in Fig.2 are in satisfactory agreement with the results of work[6].

The main data of α-activation of the target are collected in the Table. In the first two columns the isotope contents of the targets and percentage of elements are shown. The α-active products from decay chains with convenient for radiography half-life are in the third column.

By considering the different reactions of compound nucleus creations we took into account only 3 or 4 evaporated neutrons. We supposed that the evaporating of 5 or more neutrons is to be of low probability. In the fifth column the α-particles

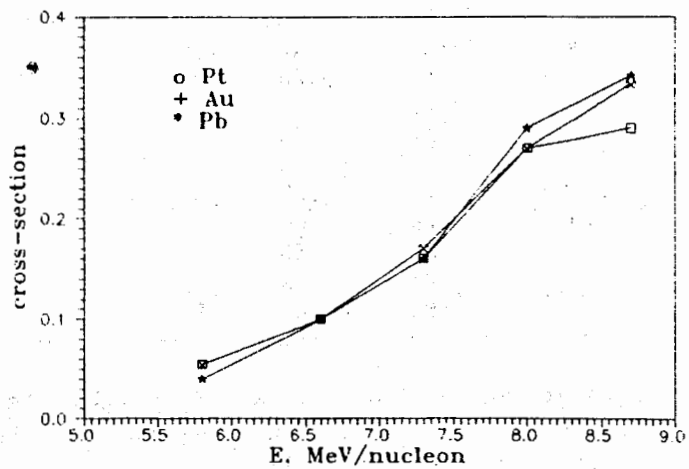

Fig.2. The backward fission fragment creation cross section σ_f of Pt, Au, Pb versus the energy of bombarding ions.

Table

Isotope	Contents in the target, %	α-active products	$T_{1/2}$	Relative yield of α-part.,%	σ_α (1.5h) barn	σ_α (144h) barn
1	2	3	4	5	6	7
^{198}Pt	7.2	^{206}Po	8.8d	5		
^{196}Pt	25	-	-	-	10^{-5}	10^{-9}
^{195}Pt	34	-	-	-		
^{194}Pt	33	^{202}Po	55m	2		
^{197}Au	100	^{205}At	26m	18	10^{-4}	$2.5\ 10^{-9}$
		^{206}Po	8.8d	5		
^{208}Pb	52	^{210}Rn	2.4h	100		
		^{206}Po	8.8d	5		
		^{208}Po	2.9a	100		
^{207}Pb	22	^{208}Po	2.9a	100	$7\ 10^{-9}$	10^{-2}
		^{211}Rn	11.6h	26		
		^{211}At	14.6hx x7.2h	30		
		^{211}Po	14.6h	44		
^{206}Pb	25	^{210}Rn	2.4h	100		
		^{206}Po	8.8d	5		
		^{211}Rn	11.6h	26		
		^{211}At	14.6hx x7.2h	30		
		^{211}Po	14.6h	44		
^{204}Pb	1.4	^{209}Rn	30m	17		
		^{209}At	5.5h	5		
		^{208}Rn	24m	20		
		^{208}Po	2.9a	20		

relative yields are shown. These yields are found to be the first order products yields $^{A+12-x}_{Z+6}Y$. We excluded from the table the products with yields less than 1%.

In the last two columns there are evaluations of the experimental effective cross sections of α-particle yields σ_α for exposure durations of 1.5 hour and 144 hours. The cross sections were estimated by formula:

$$\sigma_\alpha = \frac{2}{\rho R} \cdot \frac{M}{N_A} \cdot \frac{n}{J} \qquad (1)$$

where ρ is target density; R, 5 MeV α-particle range; M, atomic weight; J, ion flux on the target; n, surface density of tracks in detector.

In relation (1) one supposed that α-particles left the thick target in geometry described in [5], and that registration efficiency was about 1.

It was found out in the experiment that σ_α was practically independent of the ion energy in the region 7-9 MeV/nucleon. For the energy 6 MeV/nucleon, σ_α was about 0.75 from the previous one.

4. THE DISCUSSION OF THE RESULTS

As one can see from Fig.2, the fission fragment cross sections for investigated nuclei are very close to each other. For example, for the energy of 9 MeV/nucleon, $\sigma_f^{Pt} : \sigma_f^{Au} : \sigma_f^{Pb} = 1:1.15:1.18$. Thus in f.f.-radiography of Pt, Au and Pb with $^{12}_6C$ ion the excitation function proves that the yields of these elements are similar.

Let us evaluate the sensitivity of f.f.-radiography. In the case of diffuse distribution of the element in the sample the relationship between concentration of the element n_x and the surface detector track density n of fragments is:

$$n_x = \frac{2}{\rho R} \cdot \rho_x \cdot \frac{n}{\sigma_f J}, \qquad (2)$$

where ρR is fragment range in the sample; ρ_x, density of the sample. Let the minimal track density $n = 10^3\ cm^{-2}$. Then, supposing for the estimation $\rho R = 5\ mg/cm^2$, $\rho_x = 10\ g/cm^3$, $\sigma_f = 0.3$ barn, we could estimate the minimal accessible concentrations:

$n_x = 1.5 \cdot 10^{18}\ cm^{-2}$ for $J = 3 \cdot 10^{12}\ cm^{-2}$;

$n_x = 4 \cdot 10^{16}\ cm^{-2}$ for $J = 10^{14}\ cm^{-2}$;

Sometimes, it is necessary to measure the local contents of the element in mineral, the number of atoms N in local area on surface of the sample is:

$$N = \frac{n'}{\sigma_f \cdot J}, \qquad (3)$$

where n' is the fission fragment track number, which forms the spot on the autoradiogram. Let minimal track number n' = 100, then:

$N_{min} = 10^{14}$ for $J = 3 \cdot 10^{12}$ cm^{-2};

$N_{min} = 3 \cdot 10^{12}$ for $J = 10^{14}$ cm^{-2}.

From the Table one could make the next conclusions. The α-particle yields are rather different for all elements. The boundary nuclei, which could be still activated by $^{12}_{6}C$, is Au. As for Pt, its activation is practically negligible. Thus, one has the principle possibility to distinguish and to identify close elements (for example: Au-Pt). Obviously, it is necessary to select the bombardment ion for every investigated element.

The sensitivity of α-radiography could be estimated from the assumption done already. For diffusion distribution of the element, concentration n_x could be determined from equation (2) if to replace σ_f by σ_α. Let $\rho R = 18$ mg/cm^2 and $\sigma_\alpha = 10^{-2}$ barn, then:

$n_x = 10^{19}$ cm^{-2} for $J = 3 \cdot 10^{12}$ cm^{-2};

$n_x = 4 \cdot 10^{17}$ cm^{-2} for $J = 10^{14}$ cm^{-2}.

In the case of local content of element, the minimal numbers of atoms are:

$N_{min} = 3 \cdot 10^{15}$; for $J = 3 \cdot 10^{12}$ cm^{-2};

$N_{min} = 10^{14}$; for $J = 3 \cdot 10^{14}$ cm^{-2}.

Thus, the sensitivity of f.f.-radiography exceeds the sensitivity of α-radiography to about one order of magnitude. In real measurements, it is useful to apply both the methods and thus, to combine the high sensitivity of f.f.-radiography and high selectivity of α-radiography.

The spatial resolutions of both the methods depend on the fragment range and α-particle range in the sample and in the detector which are equal to 10-20 μm.

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