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A high-sensitivity, non-destructive trace element analysis

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Abstract

We have developed a new method of trace element analysis based on neutron activation analysis with multiple γ-ray detection (NAAMG). So far we utilized neutrons from research reactors but the new pulsed neutrons of Advanced Neutron Sources in JAERI and KEK collaboration will open new possibilities of NAAMG. An in-beam measurement will make it possible to identify short-lived activities so that the number of elements of simultaneous analysis becomes as many as 70. The micro beam of neutrons will be useful for the analysis of microscopic structures of various specimen.

1. Introduction

Widely used neutron activation analysis utilizes single detector to measure γ-rays from a neutron-activated sample. The energy resolution is approximately 1/1000 for a high-resolution germanium detectors. The radioactive nuclei emit more than ten γ-rays on the average so that, if the sample includes many elements, the number of γ-rays exceeds one thousand, making it difficult to resolve all the γ-rays. Weak γ-rays, in particular, are masked by strong γ-rays. The weak γ-rays, then, have generally been quantified through chemical separation or by measuring the half-lives of each nuclide separately. Chemical separations poses difficulties, however, since it not only requires special chemical analysis skills and additional steps, but also requires a determination of recovery yield. These extra operations increase the chance that errors will occur. Measuring half-lives, meanwhile, is a long process, as nuclides with long half-lives cannot be measured until the short half-life nuclides breakdown. Furthermore, the detector must be maintained in operation during the whole process, demanding much time and effort. Thus a new technique is highly desirable which achieves better resolution and makes any artificial procedure unnecessary.

In this paper, at first, we report the new technique of multiple γ-ray detection to improve the energy resolution of a γ-ray detector and its application to neutron activation analysis. And next the technique can be extended by utilising the pulsed neutron beam. The advantage there will be discussed.

2. Neutron activation analysis with multiple γ-ray detection (NAAMG)

To develop a new detection technique we took advantage of the fact that many radioactive nuclides emit multiple coincident γ-rays. By detecting the coincident γ-rays we can create a γ–γ two-dimensional matrix which incorporates the correlation among the γ-rays. We could improve the energy resolution by a factor of one thousand. This indicates that one can separate completely as many nuclides as present in a sample (even for 2700 nuclides so far found in nature).

The multiple γ–ray detection method has been used for the nuclear structure study at high excitation energy. We for the first time applied it to the neutron activation analysis of standard rock samples, JB-1a and JP-1, issued by the Geological Survey of Japan. By utilizing neutrons from the research reactor, JRR-3, and a γ-ray detector array, GEMINI [1], at Tokai JAERI, it has been demonstrated that simultaneously 23 elements can be identified without chemical separation (ref. [2]). From intensity of the two dimensional γ-ray peak we could derive the quantity of each element. It is compared with the data already compiled in ref. [3]. In this way it is concluded that the new technique gives consistent results with the previously determined ones.

The required conditions in the new technique are existence of at least one set of multiple coincident γ-rays, and the half life of produced nuclide larger than ten minutes (typical transport time from the reactor to detector position). It is concluded that 49 elements can be quantified simultaneously by this method. Another important feature is that the background can be greatly suppressed in the two diemnsional matrix and very weak γ-ray can be detected: a high-sensitivity of ppt (ten to the minus twelfth) order could be achieved [2]. Furthermore, by combining with the comparison method it was demonstrated that the quantitative results can be as accurate as in the order of percent [4].

3. Application of pulsed neutrons (PNAAMG)

The new pulsed neutron beam of Advanced Neutron Sources in JAERI and KEK collaboration is expected to open new possibilities of Pulsed Neutron Activation Analysis with Multiple Gamma-

Table I. Elements classified in NAAMG and PNAAMG

method	elements
NAAMG:	Ag, As, Ba, Br, Ca, Cd, Ce, Cl, Co, Cs, Er, Eu, Fe, Ga, Gd, Ge, Hf, Hg, I, In, Ir, K, La, Lu, Mn, Mo, Na, Nd, Ne, Ni, Os, Pt, Ra, Rb, Re, Ru, Sb, Sc, Se, Sm, Sn, Ta, Tb, Th, Ti, U, W, Yb, Zn
PNAAMG:	Ag, Al, As, Au, Ba, Br, Ca, Cd, Ce, Cl, Co, Cr, Cs, Cu, Dy, Er, Eu, F, Fe, Ga, Gd, Ge, Hf, Hg, Ho, I, In, Ir, K, La, Lu, Kr, Mg,Mn, Mo, Na, Nd, Ne, Ni, Os, Pd, Pr, Pt, Ra, Rb, Re, Rh, Ru, S, Sb, Sc, Se, Sm, Sn, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, W, Xe, Y, Yb, Zn, Zr

ray Detection (PNAAMG) extended from NAAMG by using pulsed neutrons. The advantage of PNAAMG is, at first, that short-lived activities can be measured by an off-beam measurement. The half-life of the produced activity can be as short as micro-seconds so that the number of applicable elements can be increased from 49 to 70 as tabulated in Table I.

Another advantage is that the specimen need not be transferred from the irradiation positrion to the detector position: irradiation, γ-ray measurement, and quantification can be placed at the same place (in-situ analysis). This also caused rapid quantification, because it would be possible to develop an on-line data acquisition program which can do the quantification as well.

4. **Summary**

The new method of trace element analysis based on NAAMG has the features of simultaneous determination multi-elements, high sensitivity, and high accuracy. So far we utilized neutrons from research reactors but the new pulsed neutrons of Advanced Neutron Sources in JAERI and KEK collaboration will open new possibilities of NAAMG. An in-beam measurement will make it possible to identify short-lived activities so that the number of elements of simultaneous analysis becomes as many as 70. The micro beam of neutrons will be useful for the analysis of microscopic structures of various specimen. This new technique is expected to contribute to various fields of environmental, medical, space and earth sciences, and exploitation etc.

References

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