Journal of Alloys and Compounds 253–254 (1997) 156–157

Hydrogen detection by prompt gamma-ray activation analysis (PGAA)

M. Crittin[a,*], J. Jolie[a], J. Kern[a], S.J. Mannanal[a], R. Schwarzbach[b]

[a] *Physics Department, University of Fribourg, CH-1700 Fribourg, Switzerland*
[b] *Paul Scherrer Institute, CH-5232 Villigen-PSI, Switzerland*

Abstract

A new facility for prompt gamma-ray activation analysis (PGAA) will be installed at the end of one of the cold neutron guides of the spallation neutron source, SINQ, at the PSI. One interesting feature of the proposed PGAA is the use of a neutron focusing lens which will permit two-dimensional scanning of samples and spectroscopy of isotopes having small capture cross sections. With some precautions, sensitivities on the order of a few ppm can be obtained for hydrogen.

Keywords: Prompt gamma-ray activation analysis; Hydrogen detection; Compton-suppression and pair spectrometers

1. Introduction

PGAA is an ideal technique for determining the presence and quantity of elements in samples by irradiating them continuously with neutrons [1]. The nuclei formed after neutron capture reaction by the elements in the sample have excitation energies equal to the binding energy of the added neutron. This energy is released by the emission of prompt gamma-rays characteristic for each element. The γ-rays are observed during neutron bombardment. Their energies allow identification of the elements present in the sample. The quantity of the constituent elements is determined by comparison of the γ-ray intensities per unit time with calibration standards.

PGAA can be used for the analysis of solid, liquid or gaseous samples. The method, being nondestructive, permits the use of the same sample for other experiments.

2. Experimental details

A spallation neutron source (SINQ) is in construction at the Paul Scherrer Institute (PSI) in Villigen, Switzerland [2]. It will continuously deliver thermal neutrons in channels, and cold neutrons in neutron guides. The new PGAA facility will be installed at the end of one of the cold neutron guides. A horizontal cut of this PGAA facility is shown in Fig. 1. The gamma-rays will be observed simultaneously with two spectrometers [3].

When the radiation spectra of the emitted γ-rays are complex, the lines of low energies will be superposed on the Compton continuum produced by the higher energy lines, resulting in a degradation of the sensitivity and precision. By using a Compton-suppression spectrometer, composed of a central germanium detector in a NaI(Tl)/BGO scintillator, the peak-to-background ratio is expected to be improved by an order of magnitude in the low energy region below about 2 MeV. The signals delivered by the scintillator will be used to reject electronically the Compton events. At energies higher than 2 MeV, the dominant process is the formation of electron–positron pairs with the subsequent emission of two photons of 511 keV in

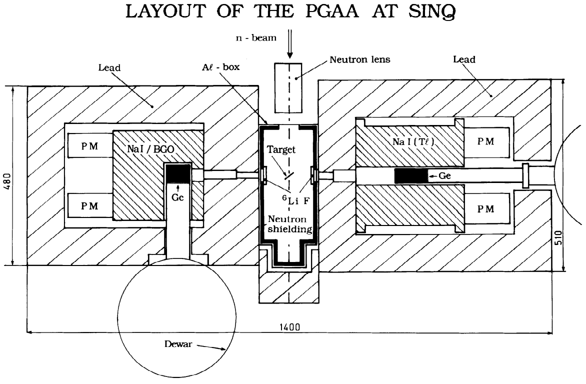

Fig. 1. Schematic plan of the PGAA at SINQ.

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*Corresponding author.

PII S0925-8388(96)02903-9

opposite directions. The pair spectrometer consists of a germanium detector placed inside the central hole of a large, cylindrical NaI(Tl) scintillator divided optically into six slices. The pair events are selected by requiring a triple coincidence condition between the central detector and two opposite slices of the scintillator. The whole detection system is well shielded against extraneous neutrons and γ-rays.

A new characteristic of the proposed PGAA is the use of a neutron focusing lens [4] which is composed of a large number of polycapillary fibres, parallel at the lens entrance and bent in such a way that all fibres converge towards a focal point. The diameter of the focused beam will be smaller than 1 mm and the flux gain will be greater than 30, resulting in a neutron flux of up to $3 \cdot 10^{10}$ n/cm^2·s at the target position. The use of this lens will permit two-dimensional scanning of samples and the spectroscopy of isotopes with small capture cross sections.

3. Applications of PGAA

Because of the low detection limits achievable for a number of elements, the PGAA method finds applications among others in solid state physics, analytical chemistry, biology, metallurgy and medicine. The PGAA is especially useful for determining the concentration of low Z elements for which the neutron capture does not produce radioactive nucleides, like hydrogen and boron. For instance, embrittlement caused by small amounts of hydrogen in metals is an obstacle to their engineering [5]. The direct measurement of ^{10}B concentration pre-injected into the tumour of patient without any pre-treatment and without large damage is indispensable in the boron neutron capture therapy for estimating the irradiation time [6].

Table 1 shows the detection limits for different elements observed at a facility in Japan [7]. Hydrogen's thermal neutron capture cross section is not very high (0.333 barns), however, each capture gives a single gamma ray at 2223.23 KeV. Consequently, a detection limit of 1 μg can be obtained if precautions are taken to avoid the presence of this element in the materials surrounding the sample.

Table 1
Detection limits obtained for certain elements using a cold neutron PGAA at a facility in Japan [7]

Element	Detection limits (μg)	Element	Detection limits (μg)
H	1	Fe	16
B	0.0023	Ni	5.1
N	95	Cd	0.0070
P	67	Sm	0.0030
S	9.4	Gd	0.0047
Cl	0.52	Hg	0.045
Mn	2.4		

Acknowledgments

The operators are open to cooperation and suggestions for specific applications. They would like to thank the PGAA team at NIST for their help in designing the facility and Dr. R. Gregory Downing for assistance in the construction of a neutron camera. The work is partly supported by the Paul Scherrer Institute and the Swiss National Science Foundation.

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