Journal of Radioanalytical Chemistry, Vol. 72, No. 1–2 (1982) 287–294

A LOW COST NEUTRON CAPTURE PROMPT GAMMA-RAY ANALYSIS FACILITY AT A RESEARCH REACTOR

J. D. JONES,* M. A. LUDINGTON,** W. L. RIGOT*

**Phoenix Memorial Laboratory The University of Michigan Ann Arbor, Michigan (USA)*
***Physics Department Albion College, Albion, Michigan (USA)*

(Received July 7, 1981)

A low cost neutron capture prompt gamma activation analysis facility has been constructed at The University of Michigan's Phoenix Memorial Laboratory. Although the neutron beam used has a fairly large epithermal component (Cd ratio 7.1), background levels are low enough to result in satisfactory measurement of over 16 different elements. For the elements of greatest sensitivity (samarium, boron, gadolinium, and cadmium) minimum detectable levels of $3.6 \cdot 10^{-5}$ to $1.4 \cdot 10^{-5}$ gram for a one hour measurement are possible. The fast neutrons incident to the detector were found to be minimal. Estimates of up to 3 years of continuous operation before measurable damage is expected.

Introduction

Over the past few years neutron capture prompt gamma analysis facilities have been developed at several research institutions[1,2]. The value of such facilities for measuring elements which cannot be done with instrumental neutron activation analysis has been demonstrated. Most of these facilities constructed with the benefit of large budgets include features such as Compton suppression systems, single crystal silicon or bismuth epithermal neutron filters, and evacuated target holders. It has been generally believed that such sophisticated arrangements as well as a large cadmium ratio are necessary in order to protect the detector from fast neutron damage and to obtain satisfactory sensitivity.

The purpose of the present study was to investigate and, if possible, demonstrate the feasibility of constructing a useful prompt gamma facility making use of available equipment and materials and utilizing the Ford Nuclear Reactor (FNR) pool-type 2 MW reactor as the neutron source.

Experimental

A top-view diagram of the irradiation facility is shown in Fig. 1.

Neutrons from the FNR 2 MW reactor were directed by means of a horizontal beam tube at targets in a collimated beam of rectangular cross-section and diagonal size 3.8 cm. The thermal neutron flux measured in the beam using gold foils was 3×10^7 n/Cm^2/sec, with a cadmium ratio of 7.1. After passing through the target the beam was stopped with a beam stop consisting of a saturated solution of borax in water followed by a boron-impregnated plastic block and several

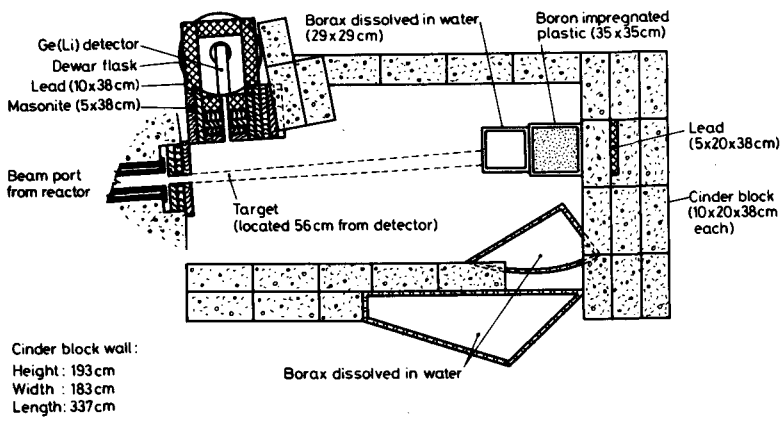

Fig. 1. Top-view diagram of prompt gamma facility

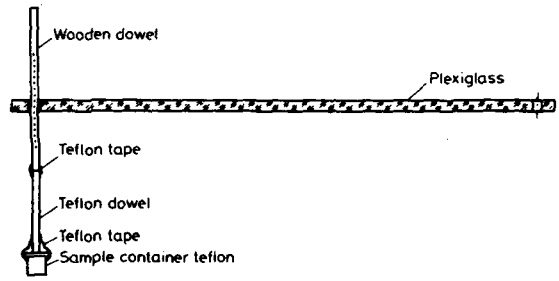

Fig. 2. Diagram of traget holder

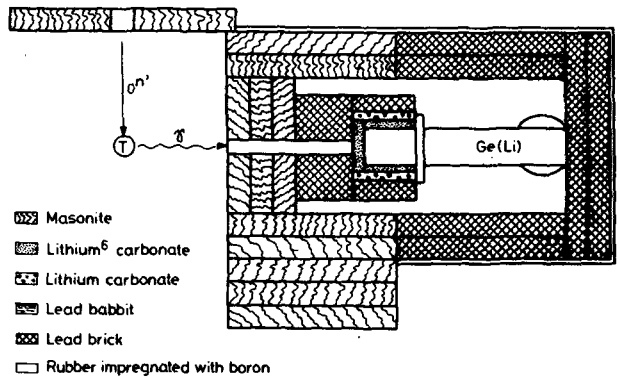

Fig. 3. Diagram of detector shielding arrangement

centimeters of lead. The entire activation facility was housed inside concrete walls to provide biological shielding.

The target arrangements are shown in Fig. 2.

Target materials were placed inside 4 ml teflon vials attached to a teflon rod suspended within the neutron beam for up to 24 hours of irradiation time. A simple cantilevered removable dowel provides a reproducible system for sample changing with minimal personnel exposure.

The detector housing is shown in Fig. 3.

Gammas produced in the target pass through a collimator of diameter 3.5 cm to the detector. The detection system consists of an Ortec VIP-10

Ge(Li) detector (10% efficient), surrounded by a coaxial shield consisting of $^{6}Li_2Co_3$, Li_2Co_3, a lead ring, lead bricks, high-density masonite, and boron impregnated rubber sheeting. The analyzer system used was a Nuclear Data 6660 computer-based multi-channel analyzer. Analysis of gamma spectra from 0.4-8.2 MeV was done using a 100 MHz ADC with a conversion gain of 8K, and 8K channels of memory per spectrum. The remaining memory of the analyzer was left free for other analytical work.

A technique for compensation of variation in beam intensity due to variable reactor conditions was adopted using a prompt gamma and its escape lines induced in the lead detector shielding. The technique reduces the frequency with which analytical reference standards need to be measured. The flux-corrected counting rate $\dot{N}'$ is given by:

$$N = \dot{N} \frac{\Sigma N_x(Pb)}{\Sigma \dot{N}_{STD}(Pb)}$$

where N is the uncorrected counting rate, $\Sigma N_x(Pb)$ and $\Sigma \dot{N}_{STD}(Pb)$ are the sum of the counting rates of the 7.66 MeV gamma-ray peak and its escape peaks from lead during the sample and standard runs, respectively.

Results and discussion

A spectrum obtained with a 750 mgm target of NBS SRM/635 coal for a counting period of 12 hours is shown in Fig. 4. Of particular interest is the boron at 104.5 ppm.

Preliminary results obtained with the present system are displayed in Table 1 which gives minimum detectable levels (Currie formula[3]) for one hour and ten hour irradiations. These elements were measured using various NBS standard reference materials.

Table 1
Minimum detectable quantities from prompt gamma analysis

Element	Minimum Detectable (gm)	
	One Hour Measurement	10 Hour Measurement
Samarium	36×10^{-6}	11×10^{-6}
Boron	33×10^{-6}	10×10^{-6}
Gadolinium	25×10^{-6}	8×10^{-6}
Cadmium	14×10^{-6}	5×10^{-6}
Chlorine	0.006	0.002
Calcium	0.006	0.002
Manganese	0.003	0.001
Potassium	0.016	0.005
Sulphur	0.04	0.03
Titanium	0.032	0.01
Silicon	0.12	0.075
Nitrogen	0.15	0.046
Hydrogen	0.32	0.1
Iron	1.0	0.32
Zinc	0.35	0.11
Aluminum	0.29	0.12

The preliminary results indicate that the system is adequately sensitive for many elements, particularly boron, cadmium, gadolinium, and samarium. Many of the elements listed cannot be measured with instrumental activation analysis. Earlier anxiety over the possible adverse effects of a high epithermal neutron component of the available neutron beam was

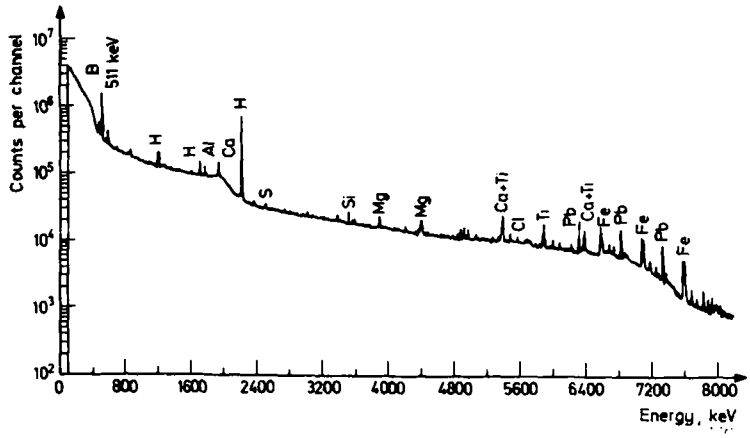

Fig. 4. Prompt gamma spectrum obtained with A SRM 635/coal target

found to be unwarranted. The background levels obtained are tolerable, although higher than might be desired. Our estimates are that the system could be run continuously for over 3 years without any detectable damage to the Ge(Li) detector. This estimate was made using a method suggested by Stetson, et. al.[4].

Possible applications

There are numerous ways in which the prompt gamma facility will prove to be a useful addition to a neutron activation analysis program. Several of the most obvious applications are noted as follows:

1. The almost instantaneous determination of many elements in one instrumental measurement makes this new technique very attractive to researchers who need results promptly, as for example those problems involving dynamic studies in chemical engineering or process control problems involving changes in the chemistry of solids. We could

easily provide on-line data reduction which would provide elemental measurements by telephonic communication to remote locations within a matter of hours after the samples were brought to the laboratory.

2. Certain elements such as samarium, gadolinium, boron, and cadmium which are only poorly determined by other techniques are easily measured by this technique and provide geologists and geochemists with valuable information useful in diffusion studies of nuclear waste material in geomedia, studies pertaining to the origin of geological formation, the inter-relationships of rock types, and many other rare earth distribution studies.
3. Rapid and accurate determination of toxic levels of the element cadmium and other elements will be possible by using small tissue or blood samples as target material.
4. Such elements as nitrogen, hydrogen, and silicon normally difficult and time consuming to measure can be routinely determined in ceramics and other materials which do not lend themselves to chemical treatment.
5. Certain alloys which have a high silicon content with aluminum can be analyzed for the silicon content by this technique. (This is very difficult by x-ray methods.)
6. There is interest in the field of botany in measuring the boron, silicon, nitrogen, and other elements in certain plants in studies directed at obtaining information on plant nutrition.

7. The measurement of hydrogen in certain materials used in fuels may be of great interest in the field of chemistry or chemical engineering.

Future improvements planned for the present system include replacing the present detector with a n-type intrinsic Germanium detector. This would result in a system much more sensitive to low energy gammas and one which could be as much as 30 times less sensitive to neutron damage.[5] In addition an automatic sample changer is proposed for the system.

In conclusion, the present investigation indicates that a prompt gamma facility is feasible at moderate cost for most research reactors. The present system is seen to be sensitive enough for many applications. With the addition of a n-type detector the system is expected to be even more useful.

References

1. M. P. FAILEY, D. L. ANDERSON, W. H. ZOLLER, G. E. GORDON, Anal. Chem., 51 (1979) 2209.
2. E. S. GLADNEY, D. B. CURTIS, E. T. JURNEY, J. Radioanal. Chem., 46 (1978) 299.
3. L. A. CURRIE, Anal. Chem., 40 (1968) 586.
4. P. H. STELSON, J. K. DICKENS, S. RAMAN, R. C. TRAMMELL, Nucl. Instr. Methods, 98 (1972) 481.
5. R. H. PEHL, N. W. MADDEN, J. H. ELLIOT, T. W. RANDORF, R. C. TRAMMELL, L. S. DARKEN, Jr., IEEE Trans. Nucl. Sci. NS-26 (1979) 321.