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Study on prompt gamma-ray spectrometer using Compton suppression system

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Abstract

The performance of the prompt gamma-ray activation analysis (PGAA) facility was improved by a series of modifications to the making composition of a Compton suppression system at HANARO, the 24 MW research reactor in the Korea Atomic Energy Research Institute. An adjustment of the crystal was made by various efforts to obtain most suitable condition for the diffracted beam, the neutron flux was increased by 20% at the sample position to 8.4×10^7 n cm^{-2} s^{-1}, and the Compton suppression ratio was 4.3–5 times below the Compton continuum region that appeared near the sample of interest such as boron. The PGAA facility at the HANARO research reactor serves as a major analytical tool for quantifying light elements in biological, geological and food samples. The sensitivity of boron is 1468 cps/mg which is obtained from the slope of the boron peak count rate versus the boron mass. For the low background conditions, a supplement to the shielding materials on the detection assembly was made and the path of the beam line reduced the background count rate, which was evaluated from the boron data using the Compton- and single-mode. From this Compton suppressed gamma-ray spectrometer, we obtained high quality spectroscopic data from thermal neutron capture.

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1. Introduction

A prompt gamma activation analysis facility has been constructed on the ST1 horizontal beam port at the HANARO research reactor, KAERI. The prompt gamma activation analysis (PGAA) is a rapid non-destructive radio-analytical technique capable of simultaneous, in situ, multi-element analysis, from light elements to heavy ones. This is also useful for performing trace element analysis for several elements with isotopes that have a sufficient neutron absorption cross section

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such as boron, cadmium, samarium and gadolinium. The elemental analysis is based on the detection of gamma-rays, emitted by the atomic nucleus right after neutron capture, i.e. (n,γ) reaction, which are characteristic of the given element. It may be completed in a relatively short time and a sample preparation procedure is not necessary. The sample is left with no residual radioactivity and can be used further without limitations. Therefore, the advantages of the PGAA are that used samples can generally be reanalyzed by other types of neutron activation analysis, and are relatively independent of sample shape, size and chemical composition and so on.

In the PGAA the gamma-radiation coming from the de-excitation of the excited states produced by neutron capture is analyzed while the sample is being irradiated. Gamma-rays produced instantaneously following neutron capture on a sample provide an unique energy and intensity signature for nearly every element. Typical lifetimes for neutron capture gamma-ray emissions are of the order of 10^{-14} s. The spectra above 10 MeV are much more complex than gamma spectra from radioactive decay, dealt within the delayed neutron activation analysis (NAA). This is partly due to the large number of gamma transitions per nuclide, which increases the probability of spectral interferences and produces complex multiplets. Moreover, many high energy gamma-rays build up a substantial Compton continuum and escape peaks which may mask weaker low energy lines. All this adds to the general problem of having a higher spectral background in prompt gamma measurements. In order to diminish these effects and improve the capability of detection, more sophisticated detection systems such as Compton suppression spectrometers have been used for micro-elemental analysis [1]. Recently, the capability of detection has been improved by advancements in thermal and cold neutron technology, the development of a new capture gamma-ray database and the advancements of the gamma-ray detection system which has also made it possible to simultaneously and precisely analyze the relative elemental composition of materials in a low background environment. From this the elemental analysis method has been applied to environmental, food, materials science, medicine, chemistry, geology analysis and other areas.

The present detection system consists of a high-purity germanium detector surrounded by bismuth germanate (BGO) scintillators to reject the Compton scattered photons. Compton scattering means that the many gamma-rays entering the germanium detector will not deposit their full energy, leading to a large Compton continuum. In order to reduce the contribution of the scattered gamma-rays the Ge detector can be surrounded by an inorganic scintillator detector. This is also shielded against neutron- and gamma-radiation background, which improves the signal-to-background ratio. It is customary to surround the main detector, usually an HPGe, with an annular guard detector. Annulus NaI(Tl) or BGO scintillators can be used, which also act as an efficient passive shielding for the main detector. The BGO detector is best suited for neutron capture measurements due to its greater stopping power compared to both the NaI(Tl) or CsI(Na), and it is less sensitive to activation and capture than the other scintillators.

The PGAA system at the HANARO research reactor has been adopted to a diffraction beam type by using pyrolytic graphite (PG) crystals. The diffracted beam profiling conditions and the neutron diffraction of the PG crystals are investigated by the BF_3 counter, laser and optical diffraction angle control methods to confirm the beam convergence rate. The effects of interference materials such as the aluminium sample holder, teflon holder and wire are investigated by measuring the elemental constituent which is monitored with the single- and Compton-mode.

2. Experimental

2.1. Experimental apparatus

The PGAA system is installed on a platform located at the exit of the 4 m long ST1 tangential beam port in the 24 MW HANARO reactor facility in KAERI. A thermal neutron beam is available by using PG crystals, which are used to