Device and software used to carry out Cyclic Neutron Activation Analysis

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Abstract. This paper discusses the device and software used to carry out Cyclic Neutron Activation Analysis (CNAA). The aim of this investigation is defining through this device the fluorite content present on different samples from fluorspar concentration plant through the DGNAA (Delayed Gamma Neutron Activation Analysis) method. This device is made of americium-beryllium neutron source, NaI (2"x2") and BGO (2"x2") gamma rays detectors, multichannel and an automatic mechanism which moves the samples from activation and reading position. This mechanism is controlled by a software which allows moving the samples precisely and in a safe way (~ms), which it is very useful when the radioactive isotopes have to be detected with a half time less than 8s.

Introduction

Neutron activation consists of bombarding a sample with neutrons for a given time, and subsequently recording or counting the gamma spectrum that is produced during a second specific period of time. In cyclic neutron activation the bombardment and counting phases are repeated for a number of times called a cycle. The number of cycles, the activation or bombardment time, and the counting time are previously determined mathematically, in order to achieve an optimal analysis. These parameters depend, among other things, on the element that one wishes to analyze [1, 2].

The basic components for the device that are needed in order to carry out cyclic neutron activation are as follows: a neutron source, multichannel and gamma ray detectors, a mechanism for transferring the sample, and an enclosure to house the source and the routes along which the sample is to move. The specific characteristics depend on the neutron reaction that will be detected.

In our case, neutron activation is carried out in order to analyze the fluorite content of samples taken from different parts of a concentration plant, using the Delayed Gamma Neutron Activation Analysis (DGNAA) method. The mining sample is fluorspar, which contains other minerals in addition to fluorite, such as silica, barite, iron oxides and silicates.

The fluorite grade in a sample is directly proportional to its fluorine grade, which is, in turn, directly proportional to the quantity of ^{16}N, produced in the reaction $^{19}F(n,\alpha)^{16}N$ [3, 4]. The sample consists of 350 g of the product, which is our case is dry ore with a granulation of less than 100 μm. The device used in neutron activation experiments is conditioned by the characteristics of the ^{16}N that one wishes to detect, and by the cross-section of the reaction.

In addition, as can be seen in Figure 1, the nuclear reaction under study has a high cross-section (on the order of 0.2 barns), whereas the energy of the neutrons hitting the sample is between 3 and 8 MeV.

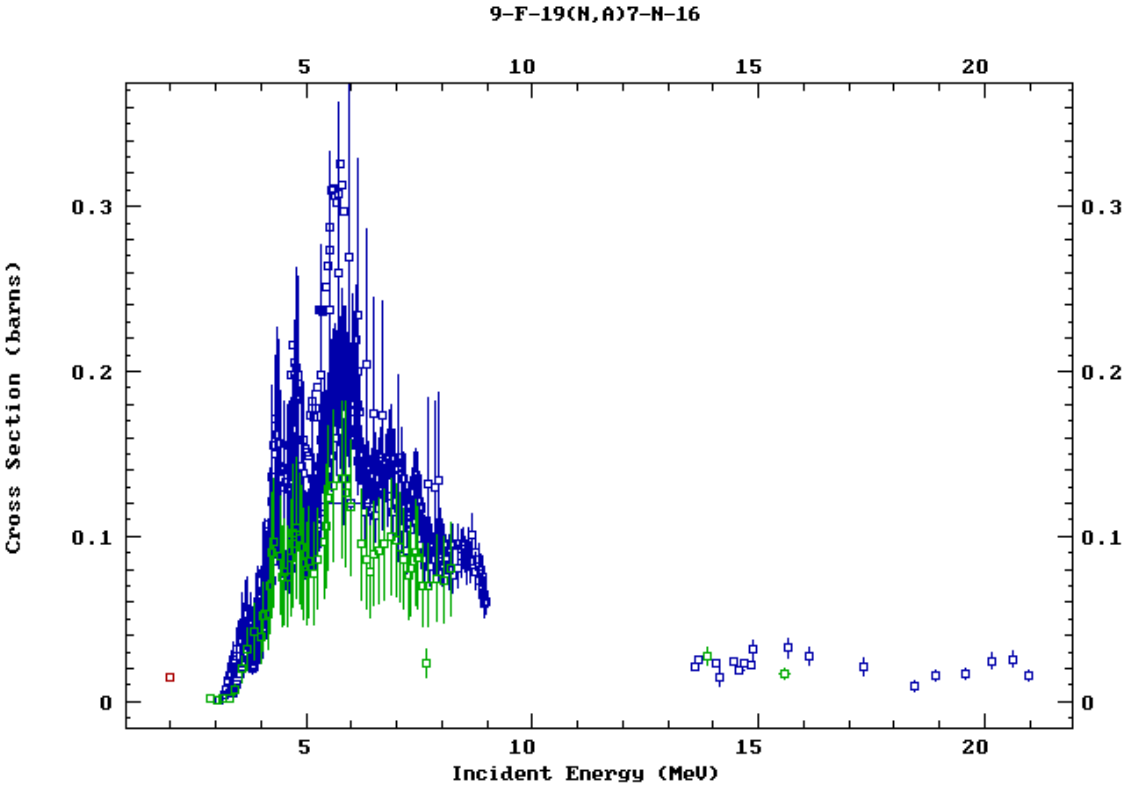

Figure 1. Cross-section of the reaction $^{19}F(n,\alpha)^{16}N$.

Furthermore, the ^{16}N has a half-life of 7.13 s, and emits high-energy gamma rays (6128 keV) as it decays.

These factors necessarily condition the various elements that make up the device needed to carry out the activation.

The neutron source that emits neutrons whose energy is between 3 and 8 MeV is an isotopic americium-beryllium source. A source that produced neutrons with a higher energy level (a neutron generator, for example), would cause the reaction $^{16}O(n,p)^{16}N$. This would bring about ^{16}N which would not have originated from the ^{19}F, and so the concentration of ^{16}N present after irradiation and the ^{19}F present in the sample would no longer be proportional. Because of this, the device is built with an americium-beryllium neutron source, with an activity of 1 Ci.

Of the different types of gamma ray detectors available, we have tested NaI and BGO detectors. Through experimentation we have found that the latter offer better resolution at high gamma energy levels (6128 KeV), such as those emitted by ^{16}N. More specifically, we have used an Osprey multichannel, which behaves better at these energy levels. The detector communicates with the computer through the program Gamma Acquisition & Analysis.

^{16}N's short half-life (7.13 s) means that the time it takes to transfer the sample from the irradiation position to the gamma ray counting station must be as short as possible. Also, the detector should be far enough away from the source to minimize the background spectrum received from the source. To this end, a borated paraffin and lead barrier should be placed in the space between the source and the detector. As a compromise between these two factors, it has been determined that the distance between the detector and the neutron source should be 700 mm.

The mathematical optimization of the process has shown that the time for irradiating the sample and the time for counting the gamma rays emitted by the ^{16}N should be on the order of 12 s each. This being the case, a high degree of control and precision is needed, not only in terms of the transfer time, but also in terms of the time that the sample stays in front of the detector or the source, as well as the exact positions that the sample is to occupy when facing the neutron source or the BGO detector.

It has been shown that over a single activation cycle, the concentration of ^{16}N produced is very low, and that the subsequent gamma ray count is very small [5]. This is overcome by employing various activation-counting cycles, in a process known as cyclic activation (CNAA) [6]. There are different ways to carry out cyclic activation, among them those discussed in the article published in the SETN-2012 conference titled, “New models for carrying out cyclic neutron activation. Discussion of theoretical response and comparison with experimental results,” which we have called *sym cyclic activation* and *asym cyclic activation*.

This type of procedure requires a sample transfer system that can handle a relatively high number of stop-and-go cycles, and is able to follow a pattern of acceleration–stop–reverse acceleration, in which acceleration and overclocking can be significant. Due both to this, and to the mass of the sample and its container, the device must be built with a durable structure that is able to withstand the stress of transferring the sample. In this case we used a Servotube linear motor joined to the structure itself, for which the movements, speeds, acceleration and overclocking of the mobile unit can be defined through a software application. The mobile unit is joined to the sample-container unit. Figure 2 shows the complete device, while Figure 3 shows the Servotube linear motor that was used.

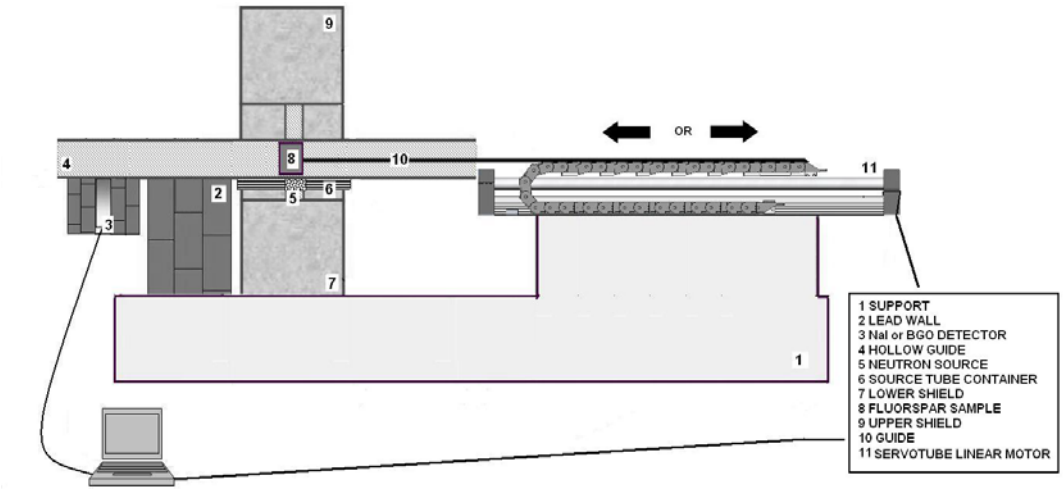

Figure 2. Device for carrying out cyclic activation.

The first step in the cyclic neutron activation procedure is to set a number of parameters: activation, counting and transfer time for the sample, the number of cycles, the detector's calibration parameters, and start and stop parameters for spectrum acquisition. The linear motor and the detector's software must be controlled simultaneously. For this purpose a software program has been developed which synchronically controls the linear motor and the gamma spectrum acquisition's respective programs. It can thus tell the linear motor to transfer the sample to the exact point where it is to be bombarded by the neutron source, and then hold that position for a set time.

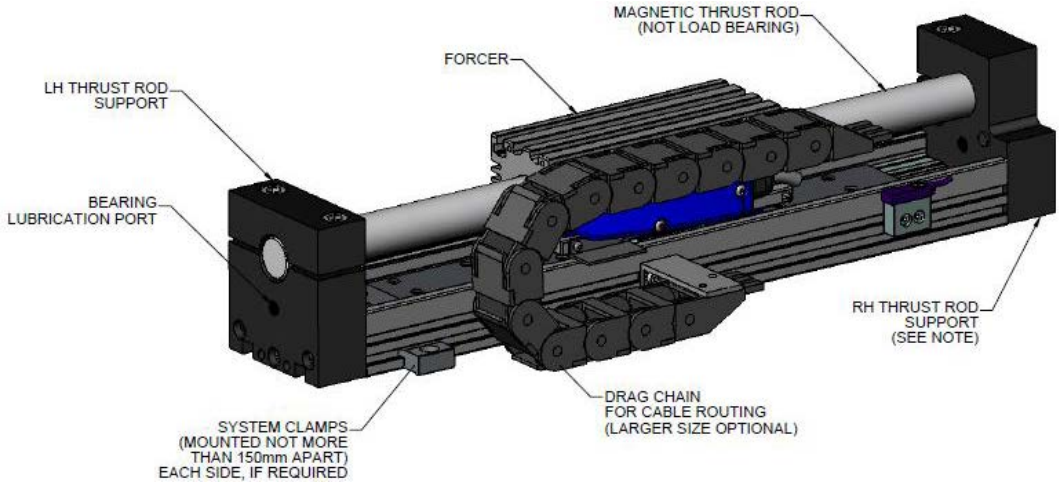

Figure 3. Servotube linear motor (source: www.mecmod.com)

After this it transfers the sample to the exact point where the detector is located, so that it can count the gamma rays emitted for another precise period of time. During this time, the program tells the detector to start reading and recording the accumulated spectrum. The new activation phase begins after the counting time is over, and once spectrum acquisition is complete. The sample's transfer times are set beforehand. A flow chart of the computer program had been designed, in which a process type is first chosen, before moving on to the

multichannel selection. After this the control data for the linear motor are entered and the program checks to confirm whether the speed and acceleration results are correct.

Lastly, the program controls when gamma ray spectrum acquisition starts and stops, but only during the time that the sample is placed in front of the detector.

With the device and software discussed in this paper, a variety of types of cyclic neutron activation can be carried out.

Conclusions

This equipment has been designed and made to carry out cyclic neutron activation of fluorite samples from a concentration plant.

It is made of a lineal motor which allows the movement of the samples between the activation position and reading position, in a precise and safe way. Besides this, the device's automation guarantees the detection of ^{16}N which has a half time of 7.13s.

The design incorporates a neutron activation of an activity of 1Ci, a Canberra INA (Tl) detector, 2 in. long and 2 in. in diameter, a Canberra BGO detector, 2 in. long and 2 in. in diameter, an Osprey Multichannel Analyzer (MCA) and a UniSpec Multichannel Analyzer (MCA) with Canberra Genie 2000 Gamma Acquisition & Analysis Software, a Servotube linear motor, 1,130 mm long, 85mm wide and 93 mm tall, with a maximum velocity of 8.7 m/s. This software allows to carry out the activation of the samples.

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