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Optimal conditions for protecting the germanium detector used in the PGNAA analysis method

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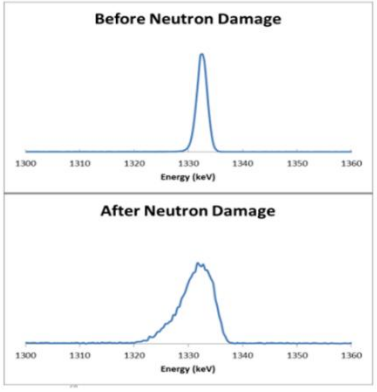
ABSTRACT

The use of high-purity germanium detectors in neutron activation analysis experiments is the best choice and may be the only one due to its ability to separate close peaks, reaching a separation capacity of 1.8 keV. Unfortunately, fast neutrons cannot be prevented from passing through it because they are more permeable than photons. It has been observed that the germanium detector loses some of its properties after being exposed to a certain dose of fast neutrons. This is due to the distortion caused by fast neutrons on the crystal structure of germanium. In the experiment proposed in this work, we aim to determine the optimal conditions for operating the analyser using Prompt gamma-ray neutron activation analysis (PGNAA) method, i.e., the conditions that maximize the number of photons incident on the detector and minimize the number of neutrons passing through it, in addition to studying the damage that occurs to the detector after being exposed to increasing doses of fast neutrons during the operation of the analyser.

Keywords: PGNAA, MCNP, Damage caused by fast neutrons to the HPGe detector, Neutrons source, PGNAA optimisation.

Graphical abstract



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1. Introduction

The method of analysis by PGNAA is based on exposing the sample to a flow of neutrons and then collecting the instantaneous photons sent by the atomic nuclei after their interaction with the neutrons [1], whether the reaction is merely an inelastic collision or another nuclear reaction. Unfortunately, nothing has been found that can prevent neutrons from reaching the gamma ray detector, and there is currently no effective detector that resists fast neutrons. It was noted a long time ago that a detector made of high-purity germanium is subjected to severe damage after being exposed to certain doses of fast neutrons. The degradation of energy resolution of HPGe detectors irradiated bay fast neutron can be explained by charge carrier trapping [2,3] caused by defect states in the forbidden band gap. The vast majority of defects are thought to be deformations of the crystal due to displaced germanium atoms causing predominantly hole trapping. In this work, we study the optimal conditions in an analysis device based on the PGNAA method using the Monte Carlo MCNP code. This device consists of a cylindrical sample irradiated by an AmBe source with an emission rate of $2.2x10^6$ n/s. Scattered gamma rays from the sample are received using an HPGe detector. The optimal geometric configuration is the configuration that enables the largest number of photons emitted by the sample to pass through the detector and reduces the flow of fast neutrons that pass through it. Then we rely on research in the literature in order to estimate how long the detector will operate safely from damage caused by the fast neutrons that pass through it.

2. Materials and Methods

The most salient characteristic of the PGNAA analysis method is that it is not constrained by the period of the radioactive element, in contrast to the NAA analysis method. Consequently, the sample can be exposed to neutron radiation for an indefinite time, thereby enabling the acquisition of a clear and readable gamma spectrum, irrespective of the sample's size and the weakness of the cross-section of the reaction. However, it is imperative to consider the extent of damage to the high-purity germanium detector when exposed to a flow of fast neutrons over an extended period [4-6]. This is what we will study in this experimental work.

The analysis device used in this work consists of a cylindrical sample holder that is irradiated by an isotopic neutron source placed close to the outer wall of the sample holder on one of the small axes of this cylinder. The photons dissipated from the sample during the time of neutron irradiation are collected using a gamma photon detector (high purity germanium), which is placed on the opposite side of the neutron source, close to the outer wall of the sample holder cylinder and also at the same horizontal level as the neutron source, Figure 1. In this work, we created a model A simulation of this device using the code MCNB. We consider, but are not limited to, a sample of water, through which we study the optimal conditions for operating this device. First, we search for the optimal sample diameter at which the sample gives the largest flux of scattered photons into the HPGe detector. We fix the thickness (height) of the sample square at 20 cm and vary its radius from 5 to 20 cm, so that each time we calculate the flux of fast neutrons and photons into the detector.

3. RESULTS AND DISCUSSION

After inserting the experimental model into the input file of the code MCNP in the P.N. mode (photon and neutron). It allows the calculation of several physical quantities, such as the current, neutrons and photons flux in the detector and sample, various reaction rates, and the dose deposed into the detector.

The distribution of photons within the detector cell, as generated by simulation using the MCNP5 code, specifically the F4:P card which gives the average flux in the cell, is shown in Figure 2. We note that the spectrum consists of a peak at 2223 keV, which is the excitation energy of a hydrogen nucleus after an inelastic collision with a thermal neutron. These thermal neutrons are formed from fast neutrons emitted by the source, which then drop in energy to less than 0.5 eV after successive elastic and inelastic collisions with the sample material. The observed photon distribution prior to this energy arises from the interaction of 2223 keV photons with both the detector and sample material through the Compton effect.

The observed photons at an energy of 0.511 MeV are the result of positron decay, resulting from the formation of a pair production effect. The lower-energy photons are the result of X-rays associated with the photoelectric effect. associated with the photoelectric effect.

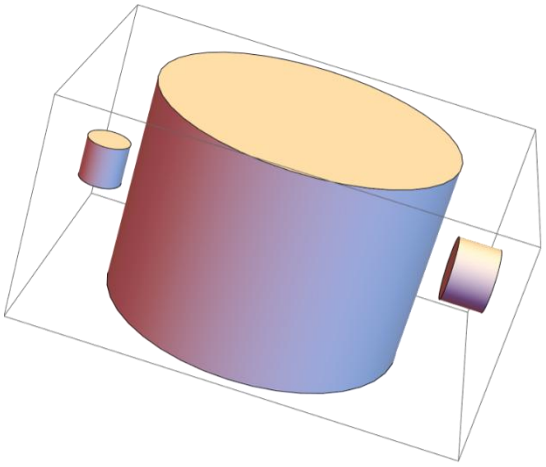

Fig 1. Structural form of the PGNAA analysis device.

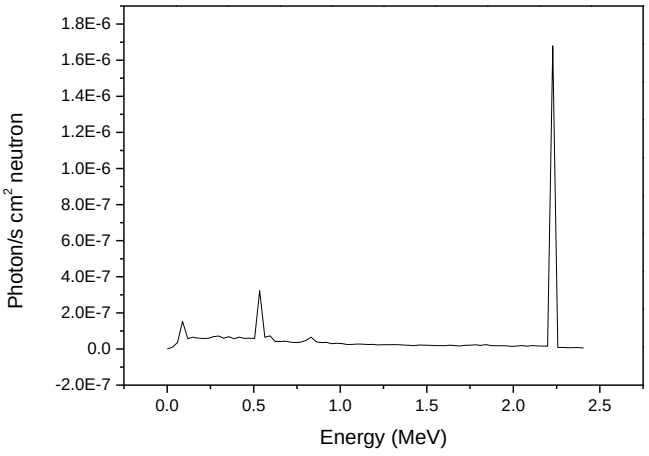

Fig 2. The spectrum of scattered photons in the detector.

According to the research presented by Ross in [7], Seabury in [8], and Seabury in [9] which confirms and supports older works such as those presented in the references [10-14]. which provides a study on the damage caused by fast neutrons on the high-purity germanium detector. the detector exposed to a neutron flux of $\sim 3\times10^{9}$ n/cm^{2} over a period of 5 days. During the irradiation, the resolution (full-width half-maximum (FWHM)) of the 1332 keV ^{60}Co photopeak increased from ~1.8 to ~6.0 keV while the full-width at tenth maximum (FWTM) increased from ~4 keV to more than 12 keV figure 3. It was also shown that HPGe detectors of p-type are more damaged than N-type

Table 1. Evolution of the flux of fast neutrons and scattered photons in the detector with sample diameter.

Diameter (cm)	Relatifs flux of neutrons	Relatifs flux of photons
10	1,07E-04	1,27E-07
14	7,66E-05	9,29E-07
20	3,49E-05	2,23E-06
24	2,09E-05	1,89E-06
30	9,54E-06	1,562E-06

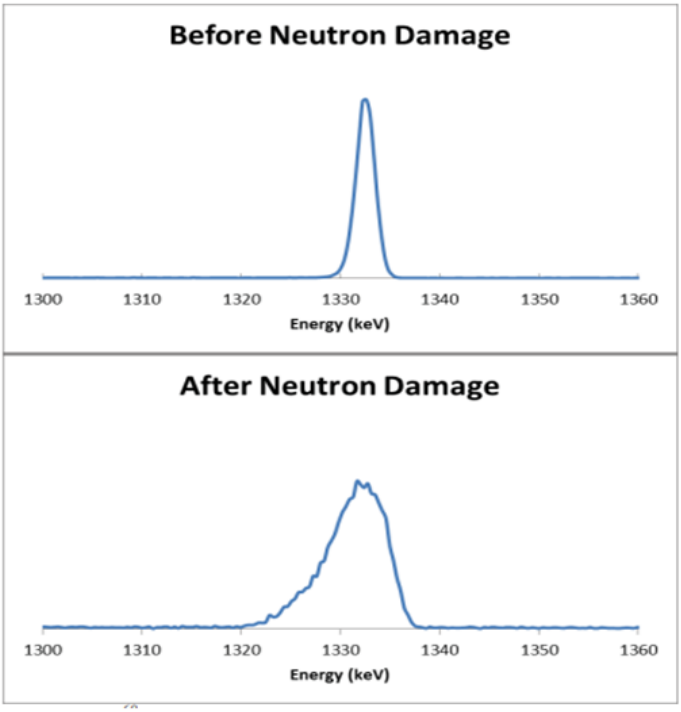

Fig. 3 ^{60}Co peak before and after neutron damage of detector [6].

4. CONCLUSION

After conducting several simulation calculations using the MCNP code, we found that the optimal diameter in the PGNAA analyses used is 25 cm. Based on previous research, it states that the harmful dose is 3x109 neutrons per cm2, considering that the neutron source has an intensity estimated at 2.2x106 n/s. We conclude that we will not reach the harmful dose until the detector is operated for 790 consecutive days. In order to be completely reassured, we must not reach a tenth of this harmful dose. However, in an experiment like this that we conducted with the used source, we can use the detector safely without the slightest fear.

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Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflict of Interest

The authors declare that they have no conflict of interest.

Data Availability Statement

Not applicable.

References

1. Ünlü K, Rios-Martinez C, Wehring BW. Prompt gamma activation analysis with the Texas cold neutron source. *J Radioanal Nucl Chem.* 1995;193:145–154.
2. Pehl RH, Varnell LS, Metzger AE. High-energy proton radiation damage of high-purity germanium detectors. IEEE Trans Nucl Sci. 1978;25(1):409–417. doi:10.1109/TNS.1978.4329341
3. Pehl RH, Madden NW, Elliott JH, Raudorf TW, Trammell RC, Darken LS. Radiation damage resistance of reverse electrode Ge coaxial detectors. *IEEE Trans Nucl Sci*. 1979;26(1):321–323.
4. Llacer J, Kraner HW. Neutron damage and annealing in high purity germanium radiation detectors. *Nucl Instrum Methods.* 1972;98(3):467–475. doi:10.1016/0029-554X(72)90230-1
5. Kraner HW, Pehl RH, Haller EE. Fast neutron radiation damage of high-purity germanium detectors. *IEEE Trans Nucl Sci*. 1975;22(1):149–159.
6. Tsoulfanidis N, Landsberger S. Measurement and detection of radiation. 5th ed. Boca Raton: CRC Press; 2021.
7. Ross TJ, Beausang CW, Lee IY, et al. Neutron damage tests of a highly segmented germanium crystal. *Nucl Instrum Methods Phys Res A*. 2009;606(3):533–544. doi:10.1016/j.nima.2009.04.024
8. Seabury EH, Van Siclen CD, McCabe JB, Wharton CJ, Caffrey AJ. Neutron damage in mechanically-cooled high-purity germanium detectors for field-portable prompt gamma neutron activation analysis (PGNAA) systems. In: 2013 IEEE Nuclear Science Symposium and Medical Imaging Conference (2013 NSS/MIC); 2013. p. 1–4.
9. Descovich M, Lee IY, Cromaz M, et al. GRETINA status and recent progress: The effect of neutron damage on energy and position resolution of the GRETINA detector. *Nucl Instrum Methods Phys Res B*. 2005;241(1–4):931–934.
10. Hull E, Xing J, Komisarcik K, et al. Radiation damage effects on high-purity germanium detectors. 1993.
11. Llacer J, Kraner HW. Neutron damage and annealing in high purity germanium radiation detectors. *Nucl Instrum Methods.* 1972;98(3):467–475.
12. Hubbard GS, Haller EE. The influence of material parameters on fast neutron radiation damage of high purity germanium detectors. *IEEE Trans Nucl Sci.* 1980;27(1):235–239.
13. Darken JR, Lawrence S, Trammell RC, Raudorf TW, et al. Mechanism for fast neutron damage of Ge(HP) detectors. *Nucl Instrum Methods*. 1980;171(1):49–59. doi:10.1016/0029-554X(80)90008-7
14. Koenen M, Bruckner J, Borfer M, et al. Radiation damage in large-volume n- and p-type high-purity germanium detectors irradiated by 1.5 GeV protons. *IEEE Trans Nucl Sci*. 1995;42(4):653–658.