

Effect of fast neutron damage on the performance of a high resolution HPGe coaxial detector

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Received 11 March 1991, in final form 20 June 1991, accepted for publication 1 July 1991

Abstract. The effect of fast neutron damage on the energy resolution and the full energy peak efficiency (FEPE) of a 157 cm^3 coaxial HPGe detector is studied. When the detector is subjected to $\sim 5 \times 10^8$ fast neutrons, the energy resolution deteriorates from 1.85 keV to 11.65 keV at 1332 keV. The FEPE decreases by $\sim 28\%$ at 80.997 keV and $\sim 8\%$ at 1332 keV with a dose of $\sim 4 \times 10^8$ fast neutrons. With the same dose of fast neutrons the total detection efficiency decreases by $\sim 13\%$, and the peak to Compton ratio (for 1408.03 keV ^{152}Eu peak) reduces to 11.7 from its original value of 70.6.

Large volume HPGe detectors are a powerful tool in gamma-ray spectroscopy, but these detectors are quite susceptible to damage when used in presence of fast neutrons. Fast neutron damaged detectors give widened asymmetric peaks with long low-energy tails in the gamma spectra [1]. This is basically due to the fact that the defects produced by fast neutrons in the crystal act as hole traps [2]. Torok [3] has suggested a simple way of determining this damage caused by fast neutrons. According to this procedure a source such as ^{60}Co is used to observe the sum peak of the two gamma rays (1173 keV and 1332 keV). If the sum peak is doubly widened and suffers a decrease in energy, the crystal is assumed to have been damaged. In this paper we report on the effect of fast neutron damage on the energy resolution and full energy peak efficiency (FEPE) of a HPGe coaxial detector having an active volume of 157 cm^3 .

This HPGe detector (EG&G ORTEC model No. GEM-30185 made of a p-type crystal) has been used for carrying out bulk elemental analysis by neutron inelastic scattering using an $^{241}\text{Am-Be}$ neutron source which emitted 1.1×10^7 neutrons s^{-1} . The detector had an initial resolution of 1.85 keV and 32% relative efficiency at 1332 keV.

The source-sample-detector geometry, used for measurement of gammas resulting from neutron inelastic scattering, is shown in Figure 1. The samples were placed directly in front of the detector at a distance of ~ 285 mm from the face of the detector and the source-sample distance was ~ 330 mm. In order to reduce the number of direct neutrons reaching the detector, a lead cylinder, 148 mm in length and 135 mm in diameter,

shadowed the detector from the neutron source. The detector itself was surrounded by lead bricks (50 mm thick) and borated plastic bricks (50 mm thick, not shown in Figure 1), which shielded it from scattered neutrons and background gamma rays. The experimental set-up was enclosed within a wooden enclosure (3050 mm in height, 2740 mm in length, and 1980 mm in breadth) in a corner of our laboratory. The enclosure was layered with borated wax bricks along all the four walls from the inside.

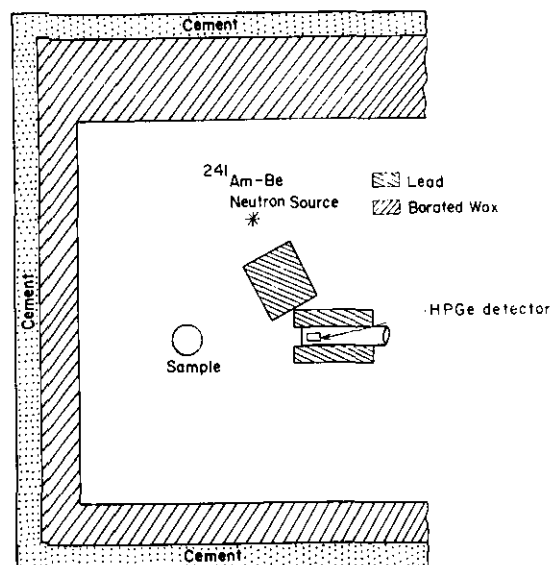


Figure 1. Source-sample-detector geometry, used for carrying out bulk elemental analysis by $(n, n'\gamma)$.

In order to demonstrate the damage to the detector we put a ^{60}Co source at a distance of 2–3 mm from the face of the detector. The resulting spectrum is shown in figure 2, where low energy tailing as well as the asymmetry can be seen in all the three peaks. The FWHM of the sum peak is 40.18 keV which is about twice the corresponding values of 21.84 and 24.11 keV for the 1173 and 1332 keV peaks respectively. The sum peak turns out to be at 2499.2 keV (according to the energy calibration) instead of 2505 keV. That is, it is 5.8 keV lower in energy. These results prove that our detector has suffered fast neutron damage [3]. In order to give an idea of the original response of the detector part of the ^{60}Co spectrum is given in figure 3.

The present detector is more susceptible to damage because it has been fabricated out of a p-type crystal. During the course of measurements involving bulk elemental analysis we observed continued deterioration of the energy resolution of the detector resulting in a FWHM of 11.65 keV at 1332 keV after an estimated dose of $\sim 5 \times 10^8$ fast neutrons. Treating the neutron source as a point, the number of neutrons incident on the sample (plastic cylinder can be filled with Si, for example) was calculated. The total number of neutrons scattered from the sample was then estimated using the fast neutron total elastic scattering cross section. Then, considering the sample as a point source of scattered

neutrons, the number of such neutrons falling on the detector was estimated. This value was then integrated over the total number of hours of neutron irradiation. In addition, the number of neutrons scattered from borated wax (along the enclosure) directly in front of the detector was also similarly estimated. The total fast neutron dose is the sum of these two. The value of the neutron dose is obviously an order of magnitude estimate and is subject to rather large errors. The deterioration of energy resolution with neutron dose has been shown in figure 4.

We had measured the FEPE of the detector at the beginning of the experiment (before using the detector in the presence of neutrons) by using a set of calibrated standard sources in a fixed source-detector geometry (source located at an axial distance of 229 mm from the face of the detector). This set consisted of ^{241}Am , ^{22}Na , ^{137}Cs , ^{57}Co , ^{54}Mn , ^{133}Ba , ^{152}Eu and ^{60}Co sources and was procured from IAEA, Vienna. The usual procedure of interpolating the background (for subtraction from the peak), by making a straight line between the channels on either side of the peak that had minimum counts, was followed for evaluating the peak areas, and no particular attempt was made to define the full base width of the peak. In fact, the statistical errors for most of the peaks were less than 1%. The resulting values of FEPE (ϵ) are given in figure 5. The continuous curve shows a least-squares fit of the data to the following function [4]:

$$\epsilon = (a_1/E_\gamma)^{a_2} + a_3 \exp(-a_4 E_\gamma) + a_5 \exp(-a_6 E_\gamma) \quad (1)$$

where a_1, \dots, a_6 are the parameters and E_γ is the gamma energy in keV.

We remeasured the FEPE of the detector in the same geometry after the latter had been exposed to $\sim 4 \times 10^8$ fast neutrons (estimated as mentioned above). These data are also presented in figure 5. Here again the continuous curve is a fit to equation (1). The parameters and χ^2 values, along with the percentage mean deviations

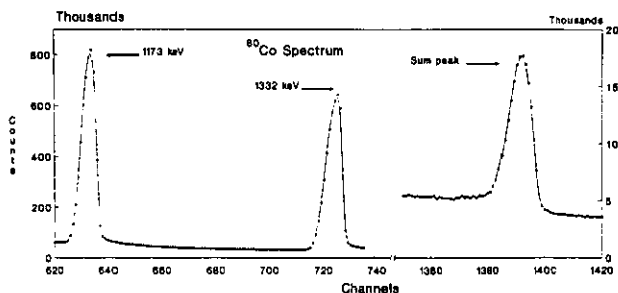


Figure 2. Plot showing the two ^{60}Co peaks and the sum peak, after the 157 cm^3 coaxial HPGe detector was subjected to a dose of $\sim 5 \times 10^8$ fast neutrons.

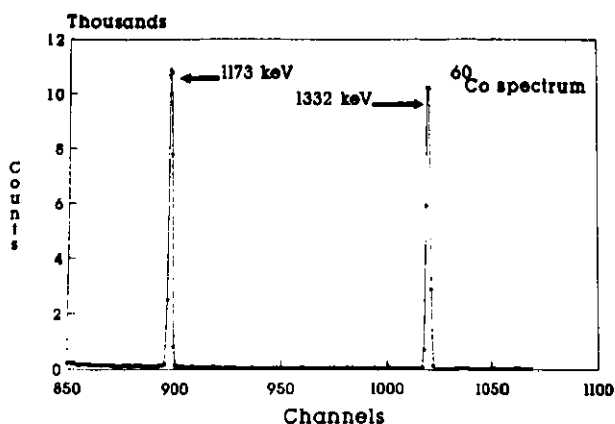


Figure 3. Plot showing the ^{60}Co peaks before the 157 cm^3 coaxial HPGe detector was exposed to neutrons.

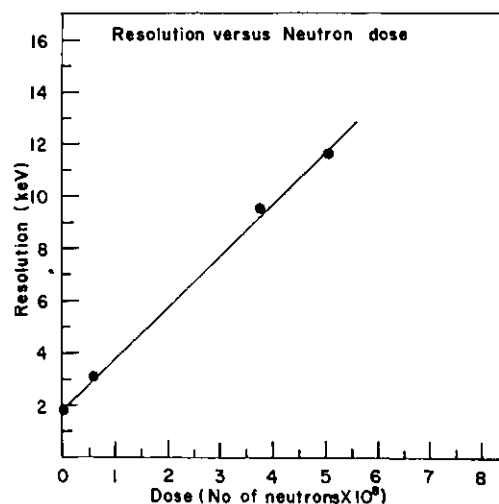


Figure 4. Plot showing deterioration of energy resolution (FWHM) of the 157 cm^3 coaxial HPGe detector, with increase in fast neutron dose.

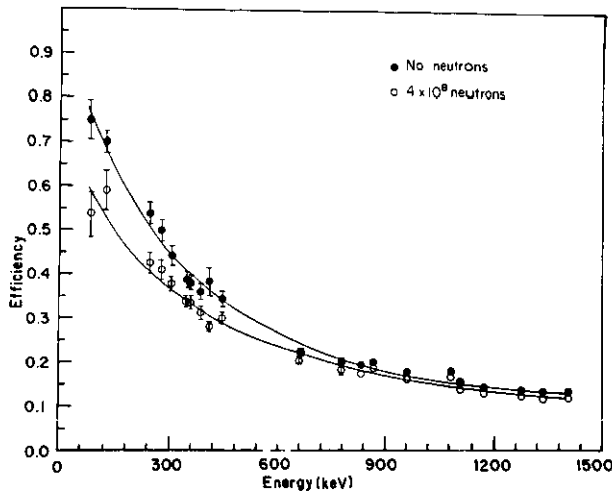


Figure 5. Plot showing degradation of FEPE of the 157 cm³ coaxial HPGe detector due to fast neutron damage.

Table 1. Parameters, χ^2 values and percentage mean deviations obtained from the least-squares fits of the FEPE data to equation (1).

	Parameters	χ^2	% mean deviation
For efficiency before neutron damage	$a_1 = 3.325365$	5.05×10^{-2}	4.14
	$a_2 = 0.565599$		
	$a_3 = 0.657909$		
	$a_4 = 0.268968 \times 10^{-2}$		
	$a_5 = 0.748956 \times 10^{-1}$		
	$a_6 = -0.65558 \times 10^{-4}$		
For efficiency after neutron damage	$a_1 = 12.85619$	9.02×10^{-2}	5.26
	$a_2 = 1.157869$		
	$a_3 = 0.459005$		
	$a_4 = 0.202740 \times 10^{-2}$		
	$a_5 = 0.856326 \times 10^{-1}$		
	$a_6 = -0.30079 \times 10^{-4}$		

obtained from the fits, are given in table 1. It should be pointed out that the large error bars in the FEPE values at low energies result from the fact that we have added the statistical error and the errors arising from the uncertainties in half-life, source strength, branching ratio, solid angle and in accounting for absorption of gamma rays in aluminium window and the inactive layer of germanium linearly, to obtain the largest possible error.

The error in accounting for absorption of low-energy gamma rays turns out to be larger. There is a considerable decrease in the FEPE values after fast neutron damage. For example, at 80.997 keV the FEPE reduces by about 28% and at 1332 keV by about 8% as compared with the original (undamaged detector) values. This is because of the fact that the effect of trapping of holes is much more pronounced on the FEPE at lower energies. In addition, a more pronounced reduction in the FEPE values at low energies points to the fact that in the given source-sample-detector geometry (see figure 1) the front surface of the detector has suffered more damage than its bulk region and, of course, the lower energy gamma rays are predominantly absorbed in the front surface region of the detector. It can be pointed out that the total efficiency (including events in the Compton distribution, measured by using ¹⁵²Eu gamma source) was reduced (as a result of damage) by ~13% and the original peak to Compton ratio (for the 1408.03 keV ¹⁵²Eu peak) of 70.6 decreased (as a result of damage) to 11.7. Present results support the belief that good quality p-type detectors are very sensitive to fast neutron damage [1]. We have demonstrated this not only on the basis of energy resolution but also by measuring the FEPE values, total efficiency and also the peak to Compton ratio.

Acknowledgments

We are grateful to the Alexander von Humboldt Foundation, Bonn, Federal Republic of Germany, for donating a Multichannel Analyser to our laboratory and to the Department of Science and Technology, Government of India, New Delhi, for financial assistance in the form of a Research Project. M Sudarshan thanks the North Eastern Hill University for the award of a Research Fellowship.

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