DESIGN AND CONSTRUCTION OF A SHIELD FOR THE 9 9 NaI(Tl) WELL-TYPE DETECTOR

by

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Technical paper
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This paper describes a homemade lead, 15 cm-thick, cylindrical shaped shield of a 9 9 NaI(Tl) gamma spectrometric well-type detector. Commercially available lead was melted into cylindrical rings. The molds for the cylindrical rings were made from hard-cooked beech wood which was pressed in a sand mold to make the final mold. After cooling, the lead rings and ring edges were sanded, transported from the foundry to the laboratory of the Department of Physics in Novi Sad, Serbia, and assembled in the detector shield. The total mass of the shield is 2622 kg. Some lines inside the shield are reduced almost 200 times and the total count rate (280 keV-3000 keV) is reduced 132.7 times.

Key words: gamma spectroscopy, detector shield, NaI(Tl), scintillation detector

INTRODUCTION

A major aspect of any nuclear spectroscopy is the minimization of background radiation not originating from the sample that is being measured. Background radiation comes from naturally occurring or man-made radioactive nuclides in the environment or from cosmic sources.

Before the creation of high-resolution semiconductor gamma spectrometers, scintillation NaI(Tl) detectors had a leading role in gamma spectroscopy. Owing to their high efficiency and the possibility of producing large and versatile shapes, these detectors are still important in many applications. Large NaI(Tl) detectors are frequently used in anticoincidence and coincidence spectroscopy where the well- or annulus-type crystal surrounds a germanium detector [1, 2].

A major aspect for setting up any detector is the selection of the detector shielding to minimize the influence of background radiation [3]. Of all the shielding materials, the most commonly used are lead and, in some cases, iron. Lead is favored against the iron due to its high density (11340 kgm^{-3}) and high atomic number ($Z = 82$).

Lead and iron manufactured after 1945, may contain fallout products such as Cs-137 and Co-60 from nuclear weapons testing in the atmosphere. Also, lead contains contamination from the primordial elements such as U-238 and Th-232 and other members of the decay chains (present in the original ore or the charcoal used in the melting process). The isotope that is of concern, especially for low-energy gamma spectroscopy, is Pb-210, with a half-life of 22.3(2) years. The Pb-210 undergoes beta decay to Bi-210, which also undergoes beta decay [4]. Beta emissions of Pb-210 and Bi-210 components in lead shielding produce a low-energy bremsstrahlung continuum, and there is also a 46.5 keV gamma emission from Pb-210. The background radiation from the shielding is undesirable especially if it is used for low activity counting and for the detection of low gamma or/and X-rays.

THE DETECTOR SYSTEM

A schematic diagram of the 9 9 NaI(Tl) detector is presented in fig. 1. All dimensions are external, apart from the dimensions of the NaI(Tl) crystal itself. Inside the 9 9 NaI(Tl) detector well, one 3 3 NaI(Tl) detector was placed. Pulses from the "big/annulus" and "small/plug" detectors are summed in the Canberra 2022 amplifier. From the amplifier, the signal goes to the Canberra Multiport II Multichannel Analyzer and than to the PC with Genie 2000 software.

Before assembling the entire system, all photomultipliers are tested individually and adjusted with a Cs-137 point source to give a signal on the same channel in the spectrum. The 9 9 NaI(Tl) detector is connected to the Canberra Model 3002-D high voltage power supply and is set to 1000 V. The 3 3

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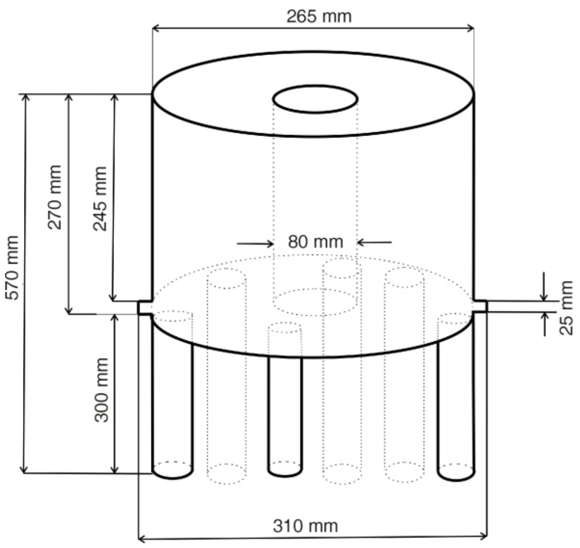

Figure 1. Schematic diagram of the 9   9 NaI(Tl) detector with 6 photomultipliers

NaI(Tl) detector has a Canberra Model 3005 high voltage power supply and is set to 680 V. Fine adjustment of high voltage on each detector is very important. Even a change of 1 V can broaden the energy line within the spectrum and deteriorate the resolution of the system. A detailed calibration of well-type NaI(Tl) detectors is described in [5].

CONSTRUCTION OF THE Pb SHIELD

The detector was surrounded by a 4   geometry 15 cm thick, low-activity lead shield. An additional 2 mm thick shield of tin and 1 mm thick shield of electrolytic copper covering the inner part of the lead shielding was added in order to reduce or eliminate the presence of characteristic fluorescence X-rays from the lead shield.

The idea was to render the shield easily assembled and disassembled. The segments of the lead shield were made in the form of lead rings surrounding the NaI(Tl) detector, of a relatively small mass (mostly about 33-40 kg, with only a couple of them up to 55 kg). The outside rings are identical around the entire shield (7 cm wide, mass 40 kg). Inside, the lead rings are 8 cm wide around the NaI(Tl) (33 kg) and 9.5 cm wide around the photomultipliers (38 kg). This arrangement of lead rings enables avoiding the use of a special holder for the 9   9 NaI(Tl) detector. The 9   9 NaI(Tl) detector has an aluminum ring around it, serving as a detector holder and as additional protection. Between the lead shield and the aluminum holder, a thin sponge was placed, because it is recommended to avoid direct shield-detector contact. If possible, the spacing between the detector and the shield should be around 10 cm. In this case, it is merely 2 cm.

The five segments below the detector are identical to the ones around the NaI(Tl) with 26 kg, 31 cm diameter lead plate in the center. The five lead segments above the detector have a smaller hole in the center for an easy sample changing within the detector well. Inside these holes, there are 2 lead lids for opening lids, with a mass of 13 kg and 14 kg. The lids are made in two parts, for easy opening by hand and to avoid the use of elevators. All of the lead rings and plates are 3 cm thick, except the ones that were casted in one piece. The lead for the shield was bought at a scrap yard in the form of old lead pipes. The total mass of the lead shield is 2622 kg.

The 80% Sn rods were bought and melted on a copper plate. The copper plate with the melted tin was then submerged in cold water; the tin instantly cooled down and divided from the copper plate in sheet form. Tin sheets were sanded to 2 mm thickness, rolled in cylinders and put between the lead shield and the copper layer. The 1 mm thick sheet of electrolytic copper was rolled around the NaI(Tl) detector.

On the laboratory floor, below the lead shield, a 10 mm thick steel plate was placed to balance the pressure on the floor. Also, below the steel plate and between the steel plate and the lead shield, to avoid any vibration, two pieces of thick triple cardboard were placed. To be sure that there will be no gap superposition between the segments through the shield, the outer cylinder was lifted for 5 mm by inserting the steel spacers below the external shield segments. Pictures of the detector and assembled shield are shown in fig. 2.

RESULTS FROM THE FIRST TESTS

When any laboratory acquires a new detector or/and new shield, it "must" first carry out quality and performances tests for the detector and shield. Also, if the factory data are available, it is recommended to compare the results from the collected spectrum with given factory specifications.

The 9   9 NaI(Tl) detector was bought in 1990 and, since in the archive of the Department of Physics, Faculty of Science, University of Novi Sad, Novi Sad, Serbia no specification from the producer exist, we have to do with the data currently available. In fig. 3, the spectra of the 9   9 NaI(Tl) detector, outside and within the 15 cm Pb shield, are compared with counts in log scale and with a marked 1460.8 keV line (K-40). In tab. 1, data on the ratio between the background spectra, with and without the shield, are given. As is shown in the last column of tab. 1 (I_{out}/I_{in}), some lines inside the shield are reduced almost 200 times. The total count rate (280 keV-3000 keV) is 132.7 times reduced and the line of K-40 (1460.8 keV) is 97.3 times reduced.

Figure 2. (a) The 9   9 NaI(Tl) detector with photomultipliers up; (b) the 3 cm wide path for cables; (c) the 2 cm narrower rings around the photomultipliers as a holder for the whole detector; (d) the 9   9 NaI(Tl) well-type detector outside the shield; (e) the Sn and Cu layers; (f) the opening for samples changing; (g) the assembled shield

Table 1. Background spectra ratio of 9 9 NaI(Tl) detector without (I_{out}) and inside the shield (I_{in})

Energy	Outside the shield	Inside the Pb shield	I_{out}/I_{in}
	t = 62565 s (30.95% dead time)	t = 517526 s (0.11% dead time)	
	I_{out} [s^{-1}]*	I_{in} [s^{-1}]	
280 keV-5000 keV	2641.0	20.8	127.0
280 keV-3000 keV	2626.5	19.8	132.7
280 keV- 600 keV	1081.6	8.9	121.5
600 keV-1000 keV	815.6	4.5	181.2
1000 keV-2000 keV	649.3	5.3	122.5
2000 keV-3000 keV	127.4	1.43	89.1
U-238/Bi-214 (609.3 keV)	313.5	1.64	191.2
Cs-137 (661.6 keV)	159.2	0.86	185.1
K-40 (1460.8 keV)	227.6	2.34	97.3
U-238/Bi-214 (1764.5 keV)	66.5	0.52	127.9
Th-232/Tl-208 (2614.5 keV)	41.2	0.54	76.3
Th-232/Tl-208 (3197.7 keV = 583.2 + 2614.5 keV)	12.2	0.32	38.1

*Count rates are corrected for the dead time

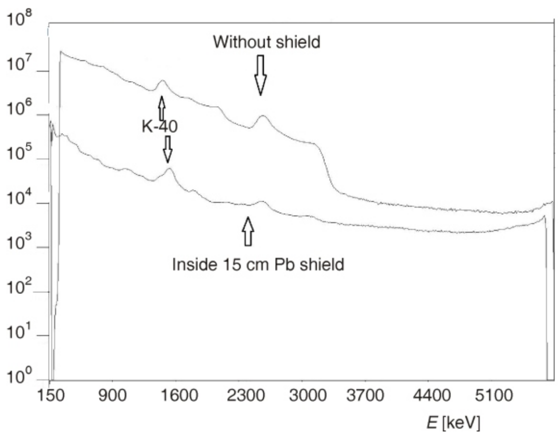

Figure 3. The 9 9 NaI(Tl) spectrum without the shield and inside the 15 cm Pb shield (log scale)

CONCLUSION

Our newly designed lead shield for the 9 9 NaI(Tl) detector exhibited a very good performance. It seems that the shielding material (lead, tin, and copper) purchased in local stores were a good choice. No traces of any contamination in the shielding materials were found. Taking into account that the exact quality of the purchased used lead was unknown, we are satisfied with the results achieved. We hope that with this addition, our gamma-spectrometry laboratory will be even more efficient in routine radioactivity measurements of environmental samples. Because of its high efficiency, the 9 9 NaI (Tl) detector has a large dead time without a shield so, in order to achieve the low minimum detectable activities (MDA), it was necessary to place the detector inside the quality shield.

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ПРОЈЕКТОВАЊЕ И ИЗГРАДЊА ЗАШТИТЕ ЗА 9 9 NaI(Tl) СПЕКТРОМЕТАР ОБЛИКА ЈАМЕ

У овом раду описан је процес изградње 15 cm оловне заштите 9 9 NaI(Tl) детектора облика јаме и резултати првих тестова. Доступно, старо, отпадно олово истопљено је у цилиндричне прстенове. Модели за цилиндричне прстенове направљени су од куваног, буковог дрвета, који су утискивани у песак за калупе, како би се начинио коначни калуп. После хлађења, оловни прстенови и ивице прстенова ошмирглани су, превезени из ливнице у лабораторију у Новом Саду, где су спојени у заштиту за детектор. Укупна маса заштите детектора је 2622 kg. Неке гама линије у спектру унутар заштите редуковане су скоро 200 пута, док је укупна брзина бројања у целом спектру (280 keV-3000 keV) смањена 132.7 пута.

Кључне речи: гама спектроскопија, заштита детектора, NaI(Tl)*, сцинтилациони детектор*
