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Original Article

# Background reduction by Cu/Pb shielding and efficiency study of NaI(Tl) detector

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ABSTRACT

The background spectrum of a 3″ × 3″ NaI(Tl) well-type scintillation SILENA detector was measured without shielding, in 6 cm thick lead shielding, and with 2 mm thick electrolytic copper covering the detector inside the lead shielding. The relative remaining background of the lead shield lined with copper was found to be ideal for low-level environmental radioactive spectroscopy. The background total count rate in the (20–2160 KeV) was reduced 28.7 times by the lead and 29 times by the Cu + Pb shielding. The effective reduction of background (1.04) by the copper mainly appeared in the energy range from X-ray up to 500 KeV, while for the total energy range the ratio is 1.01 relative to the lead only. In addition, a strong relation between the full-energy peak absolute efficiency and the detector well height was found using gamma-ray isotropic radiation point sources placed inside the detector well. The full-energy peak efficiency at a midpoint of the well (at 2.5 cm) is three times greater than that on the detector surface. The energy calibrations and the resolution of any single energy line are independent of the locations of the gamma source inside or outside of the well.



## 1. Introduction

At the beginning of the use of radioactive sources in an assortment of fields such as energy, industry, health physics, and environmental applications, nuclear radiation detectors became fundamental tools because radiation is dangerous to health. In radiation measurement, an accurate knowledge of the detector spectral performance is essential [1].

A major aspect of nuclear spectroscopy is minimization of the background radiation not originating from the sample that is being measured. Background radiation comes from naturally occurring or artificially produced radioactive nuclides in the environment or from cosmic sources [2]. The setup for any detector involves the selection of detector shielding to minimize the influence of background radiation. Of all the shielding materials, the most commonly used are Pb and, in some cases, iron. Pb is favored because of its high density (11340 kg/m$^3$) and high atomic number ($Z = 82$). In addition, a thin sheet of Cu to cover the detector is essential against X-rays, created from the interaction of radiation from the background and even coming out of the sample with the outer Pb shielding [3].

NaI(Tl) is one of the most widely used gamma spectrometry material; its performance directly depends on its detection efficiency [4], which can vary with the volume and shape of the detector material, the radiation energy, the absorption cross-section in the material, attenuation layers around the detector, and the physical thickness of the detector in the direction of the incident radiation, along with the source to detector distance and geometry [5,6].

A significant advantage of well-type NaI(Tl) crystal is its high counting efficiency, which can be achieved by placing the samples at the bottom of the well. In this position, almost all gamma rays emitted isotropically from the source are intercepted by at least a portion of the crystal [7]. The well-type is very useful in low level activity and very low mass samples, such as environmental air-filter samples [8]. It is also very efficient for low-energy gamma rays [9]. At very high $\gamma$-energies, some advantages are lost because the average path length through the crystal is somewhat less when gamma rays are externally incident on a solid crystal. Accordingly, it is necessary to know the efficiencies and resolution of well-type detectors as a function of gamma energy and the variation of the detector crystal efficiency as a function of the well depth [10,11].

In the present work, study of best shielding for an NaI detector against background radiation as well as the X-rays created by the

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main shield (Pb) is carried out. The energy and efficiency as well as resolution calibrations of the 3″ × 3″ NaI(Tl) well-type detector are established in various positions from 0.5 to 6 cm height inside the well, moving up in steps of 0.5 cm. Standard sources are used for these purposes.

## 2. Experimental part

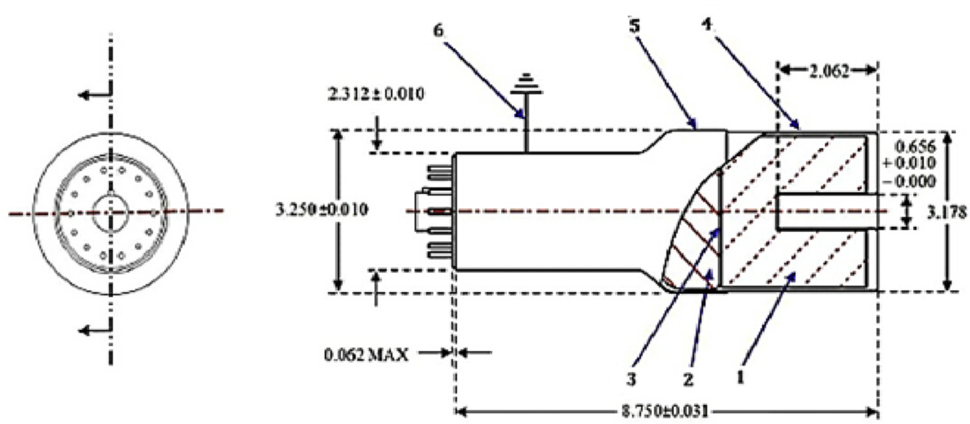
### 2.1. Construction of Pb shield

The detector is surrounded by a 4π geometry 6 cm thick Pb shield. An additional 2 mm thick shield of electrolytic Cu, covering the detector inside the Pb shield, is added to eliminate or reduce the characteristic fluorescence X-rays produced mainly by the Pb shield.

The construction of the Pb shield is done by designing an iron cylindrical mould of 16 cm inner diameter, 6 cm thickness, 22 cm height, with an upper opening. Commercial Pb rods were bought and melted on the iron cylindrical mould. Overall weight was approximately 148 kg.

The open, upper Pb cylinder is covered by a central lid surrounded by a ring; the cylinder and ring both are of 6 cm thickness and have masses of 10 and 18 kg, respectively. These lids are made in two parts, for easy opening by hand, not mechanically.


**Fig. 1.** Setup gamma ray spectrometer, (A) The 3″ ×3″ well-type NaI(Tl) detector with photomultipliers, (B) Cu layers, (C) The opening for samples changing, (D) The photomultipliers passing through the lower part of the shield, (E) Cover shield, (F) The assembled shield.




1. Crystal: 3″× 3″ NaI(TI)
2. Photomultiplier tube
3. Bicron proprietary optical coupling
4. Aluminum housing with well: Chrome finish
5. MU-Metal light shield: Chrome finish
6. Light shield grounded to pin 14 (cathode) performances: PHR<9.0% for $^{137}$Cs

| | |
|---|---|
| Energy resolution (FWHM) at 661.6 keV | 6.3% |
| Cathode to anode voltage | 820 V dc |

**Fig. 2.** The manufactory diagram of the 3″ × 3″ well-type NaI(Tl) SILENA model 3S3W detector (All dimensions are in inches).