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# Neutron Detection with Mercuric Iodide

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# Neutron Detection with Mercuric Iodide

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Mercuric iodide is a high-density, high-Z semiconducting material useful for gamma ray detection. This makes it convertible to a thermal neutron detector by covering it with a boron-rich material and detecting the 478 keV gamma rays resulting from the $^{10}B(n, \alpha)^{7}Li^{*}$ reaction [1]. However, the 374 barn thermal capture cross section of $^{nat}Hg$, makes the detector itself an attractive absorber, and this has been exploited previously [2]. Since previous work [3-6] indicates that there are no low-energy gamma rays emitted in coincidence with the 368 keV capture gamma from the dominant $^{199}Hg(n, \gamma)^{200}Hg$ reaction, only the 368 keV capture gamma is seen with any efficiency a relatively thin (few mm) detector. In this paper we report preliminary measurements of neutrons via capture reactions in a bare mercuric iodide crystal and a crystal covered in $^{10}B$-loaded epoxy. The covered detector is an improvement over the bare detector because the presence of both the 478 and 368 keV gamma rays removes the ambiguity associated with the observation of only one of them. Pulse height spectra, obtained with and without lead and cadmium absorbers, showed the expected gamma rays and demonstrated that they were caused by neutrons.

Acknowledgement
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6. D. Breitig, R. F. Casten, and G. W. Cole, *Phys. Rev. C,* **9** No. 1, p. 366, 1974.

# Neutron Detection with Mercuric Iodide

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*Abstract*- Mercuric iodide is a high-density, high-Z semiconducting material useful for gamma ray detection. This makes it convertible to a thermal neutron detector by covering it with a boron-rich material and detecting the 478 keV gamma rays resulting from the $^{10}B(n, \alpha)^{7}Li^{*}$ reaction [1]. However, the 374 barn thermal capture cross section of $^{nat}Hg$, makes the detector itself an attractive absorber, and this has been exploited previously [2]. Since previous work [3-6] indicates that there are no low-energy gamma rays emitted in coincidence with the 368 keV capture gamma from the dominant $^{199}Hg(n, \gamma)^{200}Hg$ reaction, only the 368 keV capture gamma is seen with any efficiency a relatively thin (few mm) detector. In this paper we report preliminary measurements of neutrons via capture reactions in a bare mercuric iodide crystal and a crystal covered in $^{10}B$-loaded epoxy. The covered detector is an improvement over the bare detector because the presence of both the 478 and 368 keV gamma rays removes the ambiguity associated with the observation of only one of them. Pulse height spectra, obtained with and without lead and cadmium absorbers, showed the expected gamma rays and demonstrated that they were caused by neutrons.

## I. Introduction

Mercuric iodide has a 31 year history, beginning with the first paper, in 1972, reporting its use as a room-temperature gamma ray detector [7]. From then through 1983, the maximum size of available crystals grew exponentially from 2 $mm^3$ to 10 cc [8], and Knoll [9] mentions one with a volume of 19.2 cc. Today they are routinely available with area 25 cm x 25 cm, and thickness up to a few millimeters.

When account is taken of the density and mass attenuation coefficient of $HgI_2$, large volume crystals are attractive for use in neutron detectors that rely on the detection of a capture gamma ray. Among materials with sufficient capture cross section, $^{10}B$ stands out because there is only a single gamma ray emitted subsequent to capture, and the signature is easy to analyze (although it is Doppler broadened). However, it is necessary to have a photopeak-efficient detector to take advantage of the 478 keV gamma ray from the boron reaction, and mercuric iodide, with a linear attenuation coefficient of 0.316 $cm^{-1}$ at this energy, would be expected to have reasonable efficiency.

As reported by Beyerle [2], $HgI_2$ itself will signal the presence neutrons by developing a peak at 368 keV, corresponding to emission from the first excited state of $^{200}Hg$. This gamma ray is emitted in 81% of captures and has a single interaction probability averaged over a 3 mm thick crystal of 17% (8.7% photoelectric absorption probability). It appears in the spectrum from a thin crystal precisely because the emitting state is populated by cascades producing primarily high-energy (> 1 MeV) gammas that are essentially invisible to the detector. This occurs because the total (Compton plus photoelectric plus pair production) interaction probability between 1 and 6 MeV averaged over a 3 mm thick crystal is approximately 4.6%, making it unlikely that a high-energy photon from high in the cascade interacts in a crystal simultaneously with a 368 keV photon. The attenuation coefficient for thermal neutrons is 3.13 $cm^{-1}$, implying that a 3 mm thick crystal is approximately optimal since neutron captures by mercury will occur essentially uniformly throughout the detector.

## II. Measurements

A 25 mm x 25 mm x 2.6 mm $HgI_2$ crystal (mounted in a Constellation Technology Mercury Module™) was biased at 2500 volts, connected to a shaping amplifier (12 microseconds shaping time), which was connected to an analog-to-digital converter. The gain of the system was adjusted for approximately 1 keV/channel. Data were acquired for 500 seconds.

Thermal neutron spectra were obtained by placing the detector inside a port in moderator of an Am-Li neutron source producing approximately 100 $n/cm^2/s$. The Am-Li source was contained in a W-Ni-Fe shield contained within polyethylene. A set of concentric lead (1 cm thick) and cadmium (0.5 mm thick) cups was available to attenuate the gamma and neutron fluxes present in the port. The lead cup fit inside the cadmium. Use of these cups separately and simultaneously distinguished the responses to the two radiations.

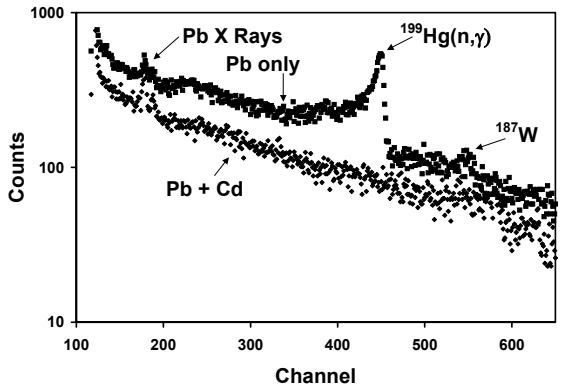


Figure 1. Spectrum from bare detector

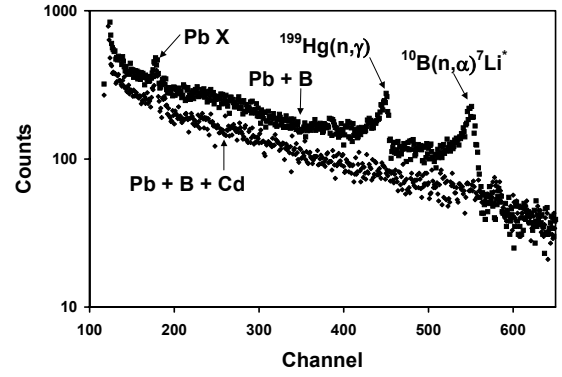


Figure 2. Spectrum from boron-covered detector

Figure 1 shows spectra obtained from a bare detector. Note the logarithmic scale and suppressed origin. The upper spectrum results from placing the detector in the lead cup and omitting the cadmium cup. The 368 keV $^{199}$Hg(n, γ) peak is clearly visible. In addition, a faint peak due to radioactive $^{187}$W (480 keV) is visible near channel 550. This isotope is produced in the W-Ni-Fe shield. The lower spectrum results from inserting the lead cup and detector in the cadmium cup. The neutron response is eliminated; fluoresced lead x rays are visible near channel 200 in both spectra.

Figure 2 shows spectra obtained from a detector covered with a 0.5 mm thick wafer of $^{10}$B-loaded epoxy. Boron loading was 32% by weight, yielding a boron density of 0.44 g/cc, and a wafer that is black to thermal neutrons. Both gamma rays are detected and are clearly visible.

## III. Conclusions

While the presence of 368 keV gamma rays is an indication of neutrons, there is no assurance that that is the only source. Lawrence Berkeley National Laboratory's listing [10] of radioactive decay gammas includes 18 lines in the range 360 – 375 keV, $^{131}$I among them. This is common medical isotope, which, although having other gamma rays, could confuse an unsophisticated analysis. Similarly, there are 22 decay gammas in the range 468 – 486 keV. However, there is only a single isotope in common, $^{192}$Ir, an industrial isotope emitting strongly at 468, weakly at 484, and even more weakly at 374 keV. Thus, although an iridium source would present gamma rays of roughly the correct energy, they would not appear in the correct ratio to be mistaken for neutrons. It would require the presence of multiple isotopes to simulate the neutron signature developed by a boron-coated $HgI_2$ crystal. However, if the simulants have different half-lives, then the simulation will become imperfect with increasing time. This scenario to fool the detector assumes, of course, that the spectrum is not analyzed for other gamma rays.

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