# APPLICATION OF PHOSWICH DETECTORS FOR LUNG COUNTING PLUTONIUM-238

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## Abstract

Mound Laboratory's Whole Body Counter was designed and calibrated for the detection of $^{238}Pu$ in the lungs. This paper summarizes the basic counting program since December 1969. The primary discussion is centered around the phoswich detection system. A unique triple coincidence pulse shape discrimination technique was used to reduce the background more than one order of magnitude as compared to a standard NaI(Tl) detector. Detection limits are given as a function of the subject's tissue thickness between the lungs and detectors. For a typical subject with an effective tissue thickness of 2.3 cm over the lungs, the system has a detection limit of 4 nCi.

## Introduction

Numerous laboratories have employes who work daily with plutonium. At Mound Laboratory about 450 employes are routinely monitored for $^{238}Pu$ as part of the overall radiological health protection program. An important part of the program is the routine and special lung counting which gives a direct assessment of the most common mode of uptake - inhalation.

This paper briefly summarizes the development of lung counting capabilities since 1969 with the primary emphasis on the phoswich detector system. The sensitivity of this system lies in the pulse shape discrimination instrumentation which is used to lower the background by more than one order of magnitude compared to a standard NaI(Tl) detector. The major problems of implementing the detector/pulse shape discrimination system are also discussed. Also included is a discussion of detection limits as a function of the chestwall tissue thickness where the chestwall is the primary absorber of low energy photons emanating from the lung.

## Historical Development

Detectors The radiation safety program at Mound Laboratory was upgraded in 1969 with the completion of the Body Counting Facility. The design of the facility was reasonably standard with a Packard Instrument Company[1] steel room and a semi-aged air supply from the crawl space in the adjacent administration building. In 1969, two standard NaI(Tl) detectors, 10.2 cm diam by 0.4 cm thick, were coupled through amplifiers to a multichannel analyzer. Room background in the 6-27 keV band was about 0.45 count/min/cm$^2$. A typical count on an unexposed individual was 0.542 count/min/cm$^2$ with a mininum detectable activity of about 11 nCi of $^{238}Pu$ (approximately 3/4 m.p.l.) using a 4000-sec count.

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A diagram of the phoswich detectors purchased from Harshaw Chemical Company[2] in July 1969 is shown in Fig. 1. By May 1970 the two phoswich detectors were in use with a significant improvement in sensitivity over the standard NaI(Tl) detectors. Room background was about 0.0185 count/min/cm$^2$ in the 14-25 keV band; however, the pulse shape discrimination system resulted in a loss of about 6% of the detected '17 keV' photons. Even so, a typical background of an exposed individual was only 0.0346 count/min/cm$^2$ (14-25 keV) which allowed a minimum detectable activity[3] ($3\sigma$ above background) of 5.1 nCi of $^{238}$Pu.

In October 1972, two additional phoswich detectors, 12.7 cm diam, were purchased; the only difference was the larger diameter of the crystals. With the same pulse shape discrimination system, the room background decreased to 0.0178 count/min/cm$^2$ and the minimum detectable activity was slightly improved at 4.0 nCi of $^{238}$Pu.

<u>Calibration Procedures</u> The most prominent photons for counting $^{238}$Pu in-vivo are the $^{234}$U L x-rays with an average energy of 17 keV. The total counts in the complete 17 keV region, i.e., from 5-28 keV, were originally integrated for analysis. However, it was soon discovered that 14-25 keV was the optimum area of integration. This was determined by maximizing $S^2/B$, where S is the net count rate and B is the background. Originally, a simple two point calibration curve was used for lung deposition assessments as shown in Fig. 2.

The two points used for the exponential fit were obtained by counting the Remab phantom[4] full and then one-half full of liquid. This gave two chestwall tissue thicknesses, i.e., two different thickness absorbers, at which the counting rate per unit activity was measured. This was knowingly in slight error for thin chestwalls because of the lung-to-detector distance with the phantom one-half

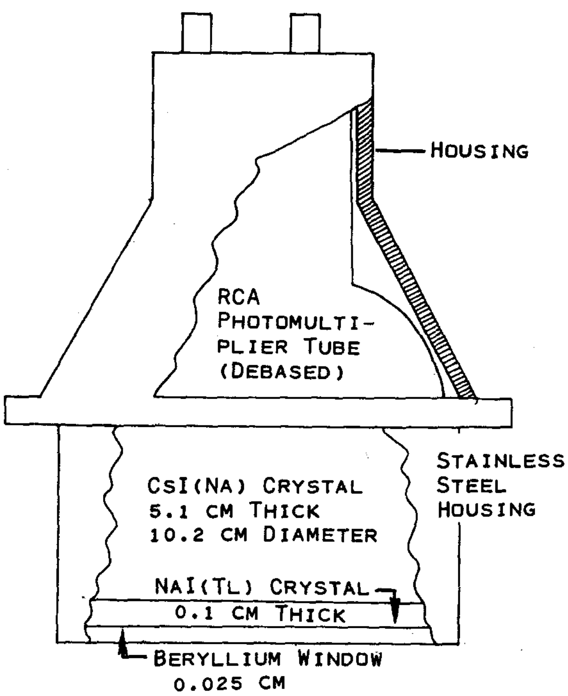


Fig. 1 Phoswich detector diagram.

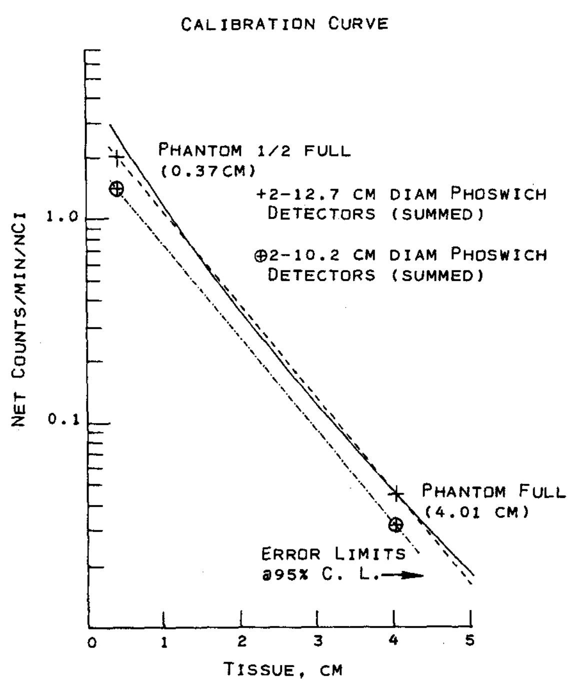


Fig. 2 Calibration curve.

full of liquid. This error was later corrected by developing the proper shaped curve using $^{238}Pu$ doped lungs from the phantom and beefsteak absorbers.[5] Once the correctly formed calibration curve existed, it was overlayed and correlated to the one suitable phantom measurement where the phantom was full of liquid and had an equivalent chestwall thickness of 4.04 cm (See Fig. 2).

Counting Procedures As part of the overall radiological health program, all plutonium workers are routinely counted on a quarterly basis. Any employe is promptly scheduled for a special lung count upon discovering 200 dis/min or more on a nasal swab. More than 50% of those needing special counts have had at least a small amount of surface contamination on various parts of their bodies. One major problem encountered in special counting is determining whether the plutonium was detected from within the lungs or from contamination of the chest surface. As little as 50 dis/min on the skin's surface can cause a false reporting of a Type B Incident. Procedures used at Mound Laboratory to eliminate "false" interpretation of data are outlined below:

1. Carrying out extremely thorough surface decomtanination, including "washing" the subjects chest with ethylenediaminetetrachloroaceticacid.

2. Placing lead loaded gloves on the subjects hands and arms.

3. Counting the subject with a lead shot filled curtain around each detector for shielding.

4. Requiring a confirming lung count taken from the subjects back.

## Instrumentation

The two phoswich detectors currently used at Mound Laboratory are summed together into the pulse shape discrimination system as shown in Fig. 3. Because of the two dissimilar crystals in a phoswich detector, each output pulse will be characteristically shaped by the crystal in which the absorbed photon lost its energy. Since the pulse shape discrimination system is aligned to accept only those low energy (17 keV) [NaI(Tl)] pulses, noise and most high energy background pulses [CsI(Na)] are rejected. About a 5-8% loss of detector efficiency has been experienced using the pulse shape discrimination system.

## Discussion

The operation of the pulse shape discrimination system is rather unique. Initially the system was set up to discriminate by using only rise time and crossover times as shown outside the dotted lines in Fig. 3. Because the room background of 0.053 count/min/cm$^2$ (14-25 keV) was not as low as expected, the system was thoroughly reinvestigated. Extraneous background counts were caused by cosmic radiation. Typical amplifier output pulses appeared similar to those shown by solid lines in Fig. 4.

Careful examination of the cosmic ray overload pulses resulted in the discovery of a preamplifier bleed-off pulse following the initial saturated pulse by 40-80 μsec. This bleed-off pulse was

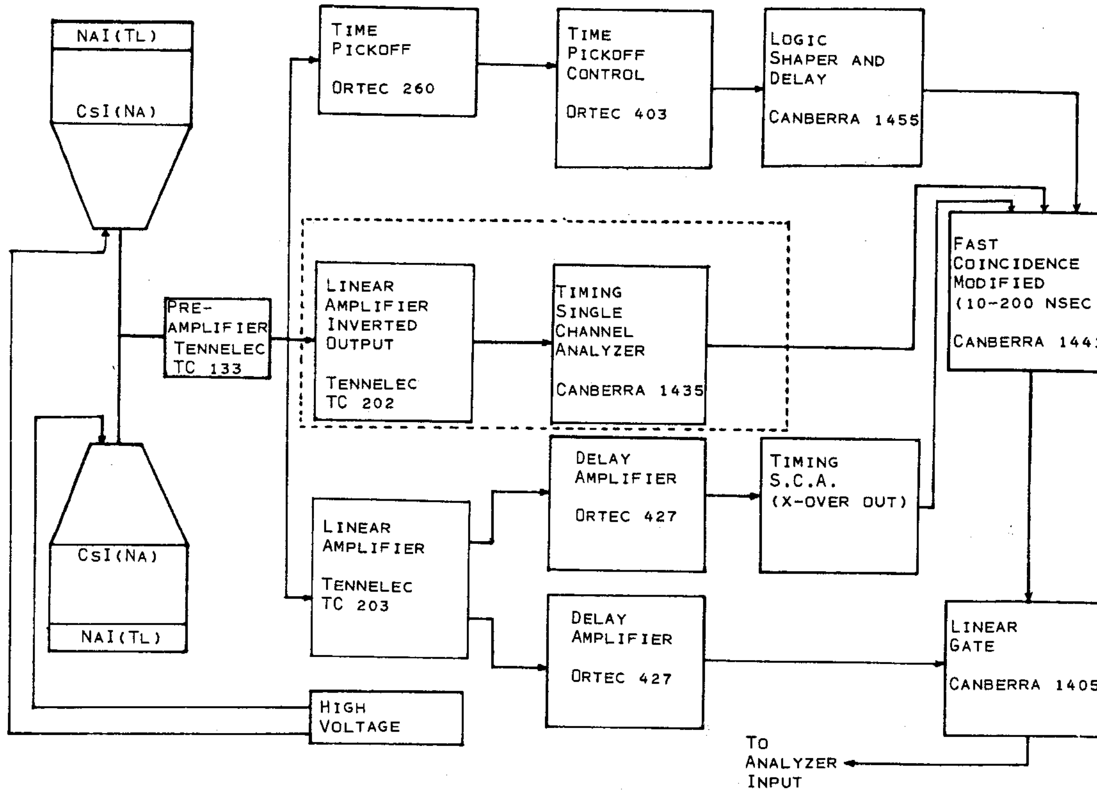


Fig. 3 Pulse shape discrimination system.

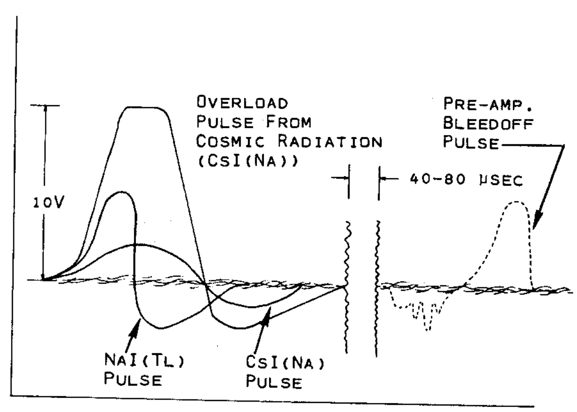


Fig. 4 Amplifier output pulses.

similar to the '17 keV' pulses from $^{238}$Pu. A portion of these bleed-off pulses would pass the discrimination system and cause extraneous background counts in the 17 keV region. Two solutions existed for this problem. The first and simplest was to use an integral discriminator to inhibit the system output for about 100 μsec after the detection of any saturating pulse. The dead time is insignificant at the count rate of interest, but can be determined. The second method (in current use) to eliminate the extraneous bleed-off pulses made use of the bleed-off pulse shape. By using an inverted bipolar pulse input to a timing single channel analyzer in the leading edge mode, only those bipolar pulses with a second lobe were accepted. (See Fig. 3).

In November 1969, efficiency measurements using the internal gate of the multichannel analyzer indicated an electronic problem in the system. The efficiency for the system decreased when the distance between the source and the detector was increased. Numerous efficiency measurements were made using the analyzer gate and then compared to results obtained under the same counting conditions with an external linear gate. The efficiency of the system using either gate was approximately 90% at counting rates of 2000 counts/min. At counting rates less than 500 counts/min, the efficiency of the system dropped to less than 50% when the analyzer gate was used, but remained at about 90% with the external gate. The unusual behavior of the analyzer gate was examined further by letting the coincidence logic pulse trigger an oscilloscope simultaneously with the linear gate in the analyzer. Observation of both the oscilloscope and the analyzer's visual display revealed that many pulses which triggered the oscilloscope did not register on the analyzer's display. Such pulses were not being stored in the analyzer's memory. It was later confirmed by the manufacturer that indeed there was a design error in the analyzer's gate. Prior to resolving the problem, abnormally low background counting rates were observed.

## Results

The comparison of a standard NaI(Tl) detector system versus a phoswich detector system of the same active area, shows an unquestionable improvement for 17 keV photons in $^{238}$Pu lung counting. A direct comparison is shown in Table 1.

Table 1

Standard NaI(Tl) Detectors Compared with Phoswich Detectors

| Detector | Steel Room Background from 14-25 keV (counts/min/cm$^2$) | Unexposed Person Count from 14-25 keV (counts/min/cm$^2$) | Minimum Detectable Activity* (nCi) |
|---|---|---|---|
| Std. NaI(Tl)<br>10.2 cm diameter<br>0.4 cm thick | 0.245 | 0.276 | 11 |
| Phoswich Detector<br>12.7 cm diameter<br>0.1 cm thick NaI(Tl)<br>12.7 cm diameter<br>5.1 cm thick CsI(Na) | 0.0178 | 0.0274 | 4 |

*3$\sigma$ above background (2.31 cm chestwall thickness).

The minimum detectable activity[3] for $^{238}$Pu lung counting has been improved by about a factor of three by changing to the phoswich detector system. The minimum detectable activity as a function of chestwall tissue thickness and unexposed subject counting rate is shown in Fig. 5.

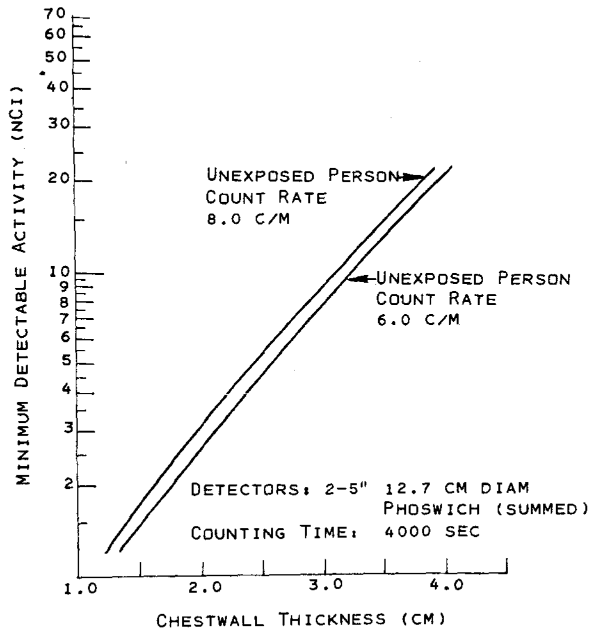


Fig. 5 Minimum detectable activity curve.

## References


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2. The Harshaw Chemical Company, Solon, Ohio, USA.

3. A Manual of Radioactivity Procedures, Handbook 80, U. S. Dept. of Commerce, National Bureau of Standards, pp 27-28 (1961).

4. Nuclear Associates, Inc., 35 Uran Avenue, Westbury, New York, 11590, USA.

5. F. Keith Tomlinson, Ralph Brown, Harold F. Anderson, and Bobby Robinson, "Chestwall Tissue Measurements for Lung Counting Applications" (Published in these proceedings.)

6. Notification, Investigation and Reporting of Occurrences, Operational Safety Handbook, U. S. Atomic Energy Commission, AEC Appendix 0502.