LETTERS TO THE EDITOR

COMMENT ON "REMOTE SENSING OF PLUTONIUM BY THE LOW-ENERGY SCATTERED FLUX"

In a recent paper, Profio and Huth[1] compare a 5-cm^2 × 5-mm-thick Ge(Li) detector to a 127-cm^2 × 1.6-mm-thick NaI(Tl) detector for the purpose of detecting plutonium at a distance.

The purpose of this Letter is to correct errors in Profio and Huth's paper in the following areas:

1. incorrect figure captions
2. mistakes in calculations of detectable mass
3. neglect of exact Poisson statistics for low count rate situations
4. a conclusion that is not supported by the data presented.

Their graphs of total flux, uncollided flux, and buildup factor for E_0 = 60 keV and 130 keV are reversed. Their Fig. 3 should be labeled 60 keV, and their Fig. 5 should be labeled 130 keV.

Their Table III summarizes their results for detectability of 60 keV photons at 100 m in air. Three of the four entries in this table are incorrect. The mistakes arise in the combination of the transport calculations with the background and efficiency data for the two detectors. (The transport calculations were not reproduced and are assumed to be accurate.) A revised table is included in this Letter (Table I). This corrected table was computed using the same technique and same input data as used by Profio and Huth with one exception: For the 127-cm^2 NaI detector in the total count mode (10- to 60-keV window), a background of 0.007 count/(s keV cm^2) was used instead of the value of 0.013 implied by their result. Because the NaI background decreases monotonically toward lower energies from its 60-keV value of ~0.013 (Profio and Huth's Fig. 13), an average background over the 10- to 60-keV region should be used instead of the 60-keV value. Pulse-height spectra taken at this laboratory with the same type NaI detector are consistent in shape and magnitude with the 0.16-cm-thick NaI spectrum presented in Fig. 13 by Profio and Huth.

TABLE I

Detectability at 100 m in Air

	5-cm^2 Ge(Li)		127-cm^2 NaI(Tl)	
	Total	Uncollided	Total	Uncollided
Source gamma/s	7.9×10^8	1.8×10^9	1.3×10^8	5.6×10^8
Plutonium mass (g)	26	59	4.4	19

A similar error arises in their calculation of the Ge(Li) detectability of the uncollided flux from a 130-keV source. Here they have used a background of 0.01 count/(s keV cm^2) instead of a value of ~0.005 appropriate to a narrow window around 130 keV (see Profio and Huth's Fig. 12).

Another type of error, also present in Table I above, appears when comparing the NaI detector with the Ge(Li). This error results from the indiscriminate application of the "3σ" detection criteria [their Eq. (2)] to low count rate situations. For the higher count rate NaI with the 10-s count time of their examples, the normal distribution approximation to the Poisson distribution can be used with moderate accuracy. The 3σ detection criterion implies a false alarm probability of 0.00135. However, for the low count rate of the Ge(Li) detector, the exact Poisson distribution must be used. For this case the 3σ detection criterion has a significantly different false alarm probability. Consider the Ge(Li) detector in a 10-s count of the 60-keV uncollided flux. The average background count is only 5. The 3σ criterion implies detection when 12 counts are accumulated (5 background + $3\sqrt{5}$ signal). Now, the Poisson probability of obtaining 12 or more background counts in 10 s, assuming an average of 5 background counts in this time, is 0.0055. This is a factor of 4.1 greater than the customary 3σ false alarm probability. Profio and Huth have compared the NaI and Ge(Li) at two quite different false alarm rates that make the Ge(Li) sensitivity appear greater that it should be. To compare on an equal false alarm probability, 0.00135 or less (the customary 3σ meaning), one needs to accumulate at least 14 Ge(Li) counts or a signal of 0.9 cps. This would change the 59-g sensitivity in Table I to 79 g.

Because the NaI detector is larger, enough counts are accumulated in a 10-s count time to make the application of normal distribution statistics reasonably valid. However, note that differences between the exact Poisson false alarm probability and the normal distribution approximation occur even for mean values exceeding several hundred counts. Table II compares the detectors using false alarm probabilities.

TABLE II

Detectability at 100 m in Air

(10-s count, false alarm probability $\leq$ 0.00135)

	5-cm Ge(Li)		127-cm NaI(Tl)	
	Total	Uncollided	Total	Uncollided
Source gamma/s	8.9×10^8	2.4×10^9	1.3×10^8	5.6×10^8
Plutonium mass (g)	30	79	4.4	19

The NaI is a factor of ~7 better than the Ge(Li) in the total flux mode. In Profio and Huth's original table, the NaI was only a factor of 3 better.

For detector comparison purposes, the problem of whether or not to use Poisson statistics can be circumvented by simply assuming the use of a longer count time or more detectors. For a 1000-s count with a single detector, the Table I detectable masses will decrease by a factor of 10, but the ratios among the individual values will be as listed. Generally, a 1000-s count time is not practical for applications involving area scanning.

The mistakes discussed above do not change the result that counting the total flux is more sensitive than counting only the uncollided flux. However, for the 60-keV uncollided flux case using the Ge(Li) detector, Profio and Huth used an unrealistically wide window of 10 keV. Since the resolution of this type of Ge(Li) detector should be $\leq$500 eV at 60 keV, a window of 1 keV or less is more realistic. With a 1-keV window and a false alarm probability of 0.00175 (close to the conventional 3σ value of 0.00135), a source strength of 0.35 cps can be detected in a 10-s count. This corresponds to 31 g of plutonium, essentially the same as is calculated for the total flux case (Table II) using the correct Poisson false alarm probabilities. Thus, for a realistic case, the Ge(Li) sensitivities are equivalent for the total flux and uncollided flux cases.

For a 1000-s count with the 1-keV Ge(Li) window at 60 keV, the detectable plutonium mass would be 2.0 g compared to 2.6 g for the total flux case with a 50-keV window. In this case, photopeak counting is somewhat better than the total flux case. Under the same conditions, the larger NaI detector is still superior because a 1000-s count of the total flux gives a sensitivity of 0.44 g. Neither calculation takes into account the effect of the higher energy gamma rays of the plutonium source on the background and signal in this region.

Finally, Profio and Huth conclude that although the NaI detector is 25 times larger than the Ge(Li), its sensitivity is only 3 to 4 times larger. They imply that this means that there is something inherently better about the Ge(Li) compared to the NaI There is nothing magic about this result. Since both detectors have nearly the same efficiency and background per unit area, the only difference in their sensitivities for the total flux case arises from their surface area difference. It is easily shown that detection sensitivity for a fixed count time and source detector geometry is proportional to the square root of the detector area. For these two detectors, the NaI is expected to be a factor of ~5 more sensitive than the Ge(Li) in a mode involving equal windows.

Compare the total count mode sensitivity for the Ge(Li) and the NaI. Assume a count time sufficient to give normal distribution statistics (Table I ratios apply). The ratio is 26/4.4 or ~6. The difference between this factor of 6 and the expected factor of 5 is solely attributed to the different backgrounds used: 0.01 cps/(keV cm^2) for the Ge(Li) and 0.007 cps/(keV cm^2) for the NaI.

The 127-cm^2 NaI detector is clearly superior to the 5-cm^2 Ge(Li) detector for the remote detection scenario. The difference arises almost entirely from the larger surface area of the NaI detector. The inherent low background of the Ge(Li) construction materials is not an advantage in this problem since the detector must be unshielded, or at best, 2π shielded for remote sensing. In this case, the natural background radiation entering the unshielded portion of the detector overwhelms any background arising from detector construction materials.

On a cost basis, the superior performance of the NaI detector will cost ~5 times less than the Ge(Li) (unit cost). For approximately equal sensitivities (equal detection areas), the NaI will cost ~125 times less than the Ge(Li), since 25 Ge(Li) detectors are required to equal a single NaI detector.

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REFERENCE

1. A. E. PROFIO and G. C. HUTH, "Remote Sensing of Plutonium by the Low-Energy Scattered Flux," *Nucl. Technol.*, **26**, 340 (1975).

REPLY TO "COMMENT ON 'REMOTE SENSING OF PLUTONIUM BY THE LOW-ENERGY SCATTERED FLUX' "

Sampson[1] has made a number of corrections and comments on our paper, some of which we agree with and some of which we do not. Many of his "corrections" are based on different assumptions rather than mistakes on our part.

He is correct in pointing out that the captions on Figs. 3 and 5 were reversed. However, the correct flux values were used in our analysis.

Average background count rates were used in some of our detectability calculations. To be consistent, we agree it would be better to use the energy-dependent background data presented in Figs. 12 and 13. But this reduces the minimum detectable source strength and