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Evaluation of Commercial Detectors

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ABSTRACT

In support of national security, it is important to develop a technical understanding of handheld gamma-ray detectors used by field teams. Several commercially available detectors have been examined to determine their efficiency profile, resolution, stability, and ability to correctly identify a variety of isotopes.

INTRODUCTION

Several handheld detectors with isotope identification ability have been evaluated. Spectra have been acquired for a number of different radioisotopes using these detectors. These spectra were used to determine efficiency profiles and calibration stability information, and to assess the accuracy of automated isotope identification, with discouraging results. This paper is an extension of the work released in the paper "Evaluation of Handheld Isotope Identifiers" [1].

INSTRUMENTS

The seven instruments used in this evaluation were a Berkeley Nucleonics Corp. SAM 935 with firmware version 02.07.02, a Quantrad Sensor Ranger with firmware version 3.12, an Exploranium GR-130 with firmware version 5.15, an Exploranium GR-135 with firmware version 1.16, a SAIC Radsmart with firmware version E, a Bicron FieldSPEC with firmware version 3:826A, and a CZT Palm Pilot spectrometer (CZT-PP) with firmware version 1.1a. The Radsmart is a CsI-based instrument, the CZT-PP is a CZT-based instrument, the GR-135 had both NaI and CZT detectors, and all of the other instruments are NaI detectors. All of these detectors are off-the-shelf models with the exception of the CZT-PP, which was a demonstration unit provided by the developers. Most of the detector manufacturers are continually improving their products, so the results may differ between the firmware versions used in this work and subsequent versions available for purchase, especially for nuclide identification accuracy.

Generally, the data from all of the detectors using a specific source were acquired simultaneously for the same duration and distance with the detectors arrayed around the source on a horizontal table. Usually the acquisition time was 5 minutes (live time) and the source-to-detector distance was 20 cm. For the detectors that do not have the ability to set a preset acquisition time, every effort was made to stop the acquisition when the other instruments stopped. It should be noted that these results do not necessarily represent the optimal performance of these instruments for identifying isotopes.

DETECTION EFFICIENCY

The intrinsic efficiency profiles (recorded counts per gamma ray incident on the detecting material) have been measured. Between 13 and 19 peaks from 4 to 8 calibrated sources were used for each of the detectors and the peak areas were fit to a standard four-parameter efficiency model of

$$\text{Efficiency} = \exp(C_0 + C_1 \cdot \ln(E) + C_2 \cdot (\ln(E))^2 + C_3 \cdot (\ln(E))^3),$$

where E is energy and C_0, C_1, C_2, and C_3 are the fitting parameters. Figure 1 shows the superimposed intrinsic efficiency curves for each of the instruments used in this study. Because of the similarities in detecting materials, the intrinsic efficiency for each of these instruments is approximately the same.

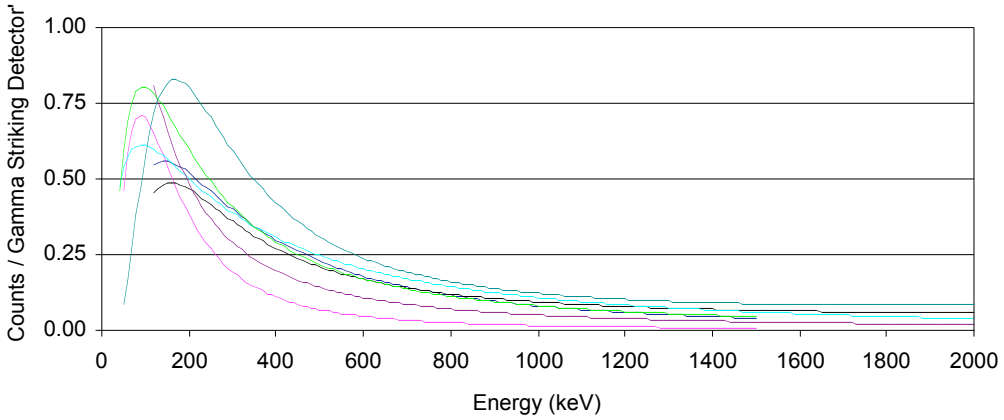

Fig. 1. Intrinsic efficiency curves for all of the instruments used in this study.

The intrinsic efficiencies were converted to absolute efficiencies for a source-to-detector distance of 25 cm and plotted in Figure 2. Because of the differences in crystal sizes, the absolute efficiencies vary significantly.

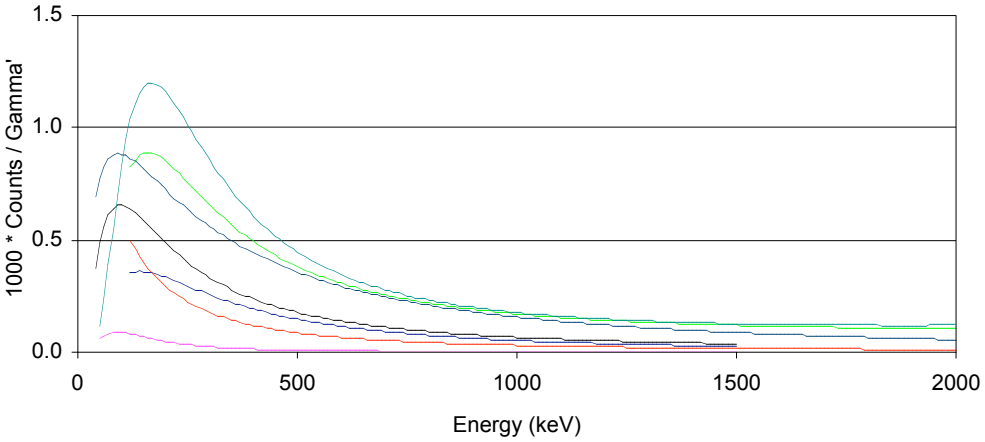

Fig. 2. Absolute efficiency curves for all of the instruments used in this study.

DETECTOR RESOLUTION

The detector resolution response as a function of energy was also extracted from the spectra. The full width at half maximum (FWHM) values for 10 to 19 peaks from 4 to 8 radioisotopes were obtained from gaussian fits and plotted as a function of gamma-ray energy. Figure 3 shows the data from one of the detectors with a quadratic trend line fit through the points. Figure 4 shows the quadratic trend lines from all of the instruments superimposed on a single plot. Figure 4 shows that the resolution response for most of the detectors is similar, but the best resolution is achieved by the CZT-based instrument.

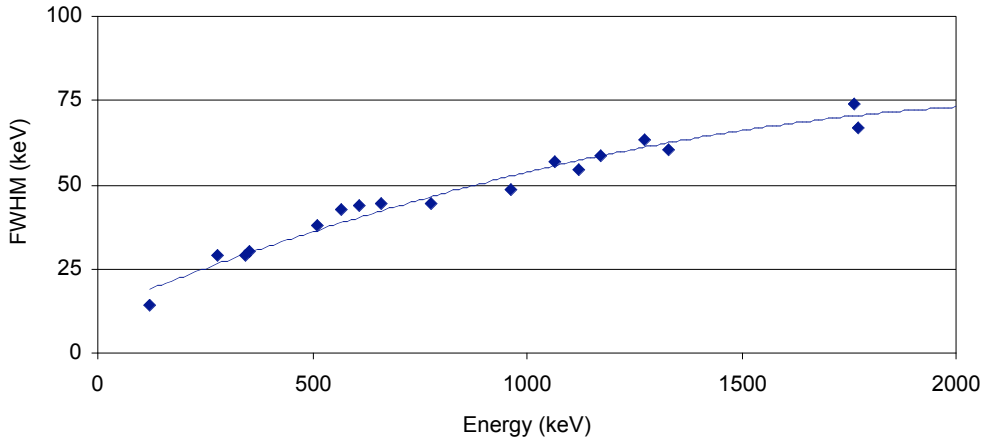

Fig. 3. Resolution data for one of the instruments with a quadratic trend line.

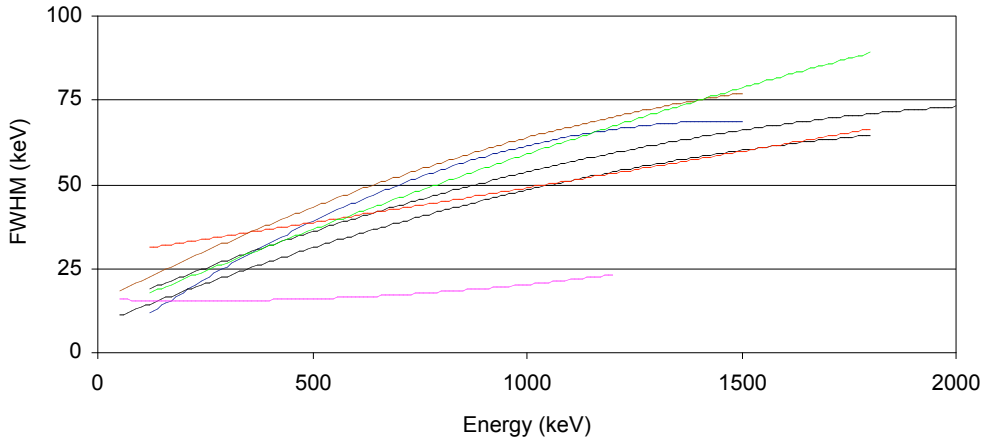

Fig. 4. The detector resolution trend lines for each of the detectors examined in this study.

CALIBRATION STABILITY

All of the spectra were manually calibrated. In the process of calibrating the spectra, it was observed that generally the calibrations of the spectra were fairly consistent from day-to-day and month-to-month. However, there could be noticeable drift from spectrum to spectrum acquired during a single session even though the instruments were generally allowed to warm up for 30 minutes before collecting any data. For each of the detectors except the SAM 935 (which uses a quadratic energy compression), a linear energy calibration was obtained from a fit to several peaks from multiple spectra. It was found that with this single calibration equation, all of the spectra for a particular instrument could be reasonably well calibrated. The exception was that one of the instruments on one day seems to have a calibration that was significantly different from the calibration for that instrument on other days and so a separate calibration equation was fit for that instrument on that day.

Twenty-four to 83 peaks from the spectra of 5 to 12 radioisotopes were fit with gaussians and their peak centroid channels were noted. The expected centroid channel numbers for these peaks were

determined from the known peak energies [2] and the linear calibration equation for each instrument. The difference between these expected and fit values was determined and plotted as a function of accepted peak energy in Figure 5. The parabolic trends that can be seen in some of the plots indicate nonlinearity in the instrument's energy response. Figure 5 shows the plots for all of the detectors except the SAM 935. It should be noted that the vertical axis is not the same for all of the instruments. Figure 5 shows that all of the instruments exhibit some scatter in energy calibration. For many of the instruments, this scatter is approximately 5 channels or less. However, some of the instruments exhibit large scatter in the data. For instruments that utilize a fixed region of interest method to determine the peak identity, the larger the scatter in peak location the more difficult it is to accurately identify the peak.

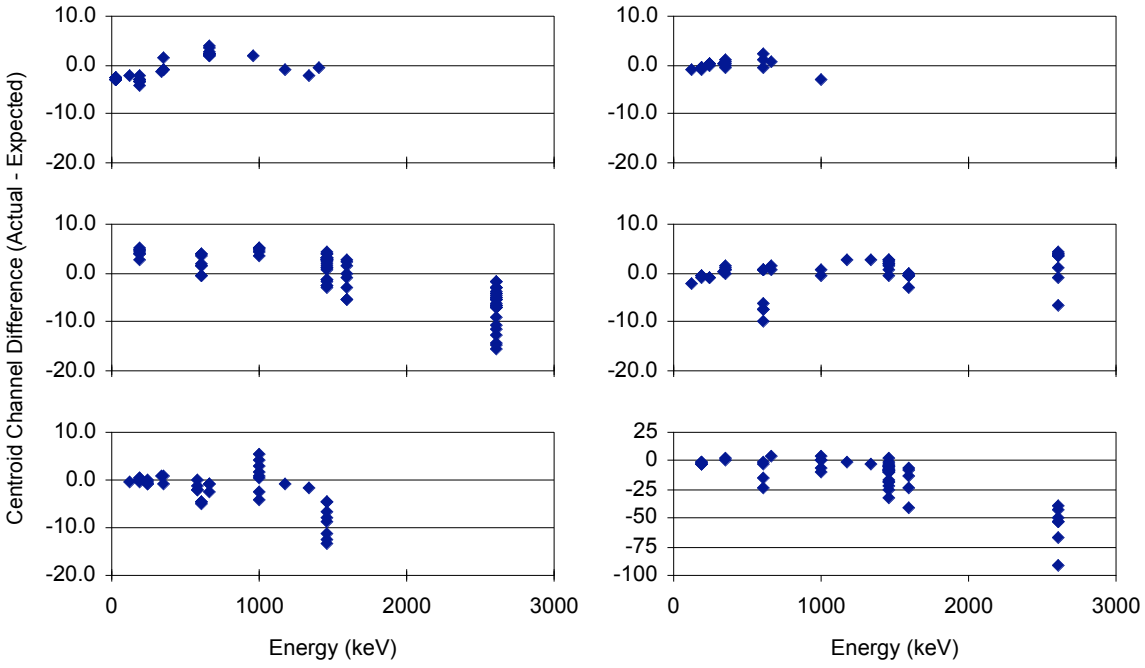

Fig. 5. Difference in actual peak centroid channel number and expected peak channel number based on linear calibration equations for each instrument. Note: the vertical scale varies.

IDENTIFICATION ACCURACY

At the conclusion of the data acquisition period, the spectral data were saved and the instrument's isotope identification was recorded. Categorizing the correctness of an instrument's identification is a complex issue. Although an American National Standards Institute (ANSI) standard for handheld isotope identifiers is under development [3], the authors are unaware of an accepted and appropriate means of performing this task. Five categories describing correctness were defined and are proposed for this. The term most abundant isotope(s) (MAI) refers to the radioisotope(s) that is (are) present with an atomic abundance of at least ~10%.

- The category of correct (C) means the instrument correctly identified at least one MAI present as the isotope identified with the most confidence or with confidence less than only a minor daughter (see definition below). Or, in the case of background, it means it identified either nothing or only ^{40}K (which is naturally in the environment).

- The category of conditionally correct (CC) means at least one MAI present was correctly identified, but with less confidence than something that was not present or could not be identified.
- The category of minor daughter (MD) means that a daughter or a non-present parent of a MAI was identified, but the instrument failed to identify a MAI or it identified a radioisotope known to be present with less than 10% abundance. Examples of MDs are identifying ^{226}Ra when the source was ^{238}U, or identifying ^{232}Th when the source was ^{228}Th.
- The category of false negative (FN) means the instrument gave no identification other than ^{40}K when a radionuclide was present.
- The category of false positive (FP) means the instrument incorrectly reported one or more radionuclides as being present without making any correct identification other than ^{40}K.

Most of the instruments give some numeric value when they make an identification. The Radsmart and GR-130 give the number of counts assigned to each isotope, the SAM 935 and CZT-PP give a correlation value from 0 to 1, the Fieldspec gives a confidence value from 1 to 10, the GR-135 gives the counts assigned to each isotope in "Standard-Deviation units." Because the Ranger does not give any confidence ranking when in the multiple isotope mode, its identifications were classified as "correct" if an MAI was present in its list of identifications.

A false negative often means the spectrum had insufficient statistics for an identification to be made, or that the radioisotope was not in the instrument's library. Because of possible sensitivities, the results from individual instruments are not being reported here. Figures 6–9 show combined identification results from all of the detectors.

A table showing the matrix of sources and detectors used in this work is included in reference 1. There were 443 independent measurements (Figure 6) made with the seven different instruments (eight detectors because the GR-135 has both CZT and NaI detectors). The number of measurements made with a particular detector ranged from 18 to 93. Fifty-eight of the measurements were background measurements (Figure 7) and 75 were of activation foils, neutron sources, and beta sources (Figure 8). The remaining 310 measurements (Figure 9) were of special nuclear material (SNM) including plutonium, enriched uranium, and neptunium, industrial sources, and medical radioisotopes.

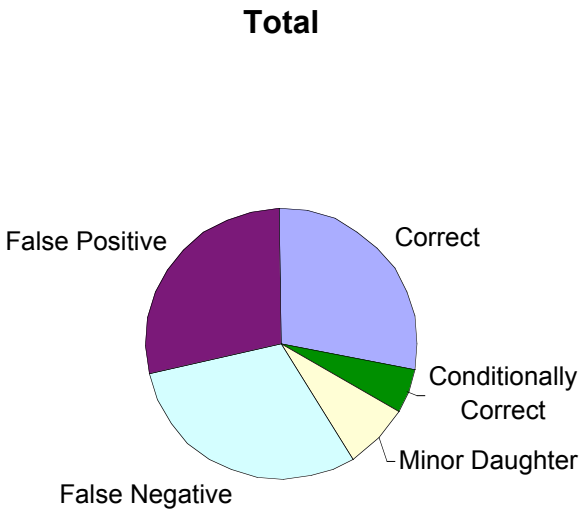

Fig. 6. Identification results for all of the detectors and data combined (seven instruments, 443 measurements).

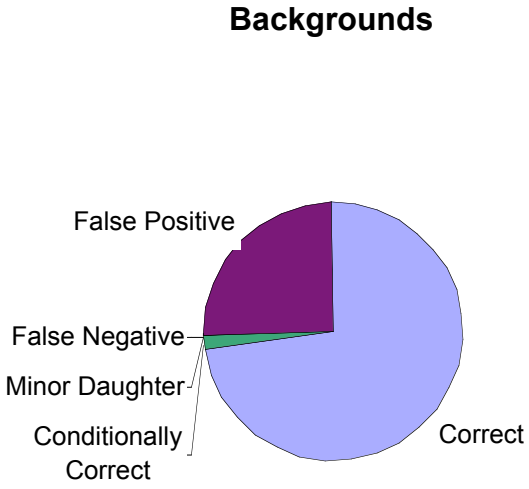

Fig. 7. Identification results for the 58 background measurements.

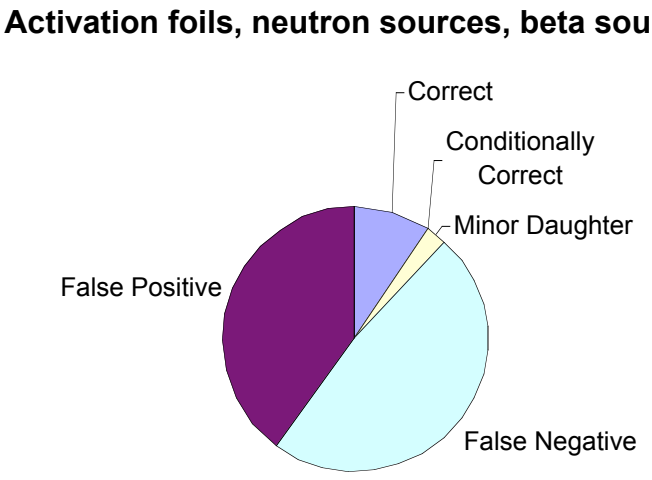

Fig. 8. Identification results for activation foils, neutron sources, and beta sources (75 measurements). Most instruments were not designed to identify neutron or beta radioactivity, and the activation foils represent exotic radionuclides that are not likely to be found in the field.

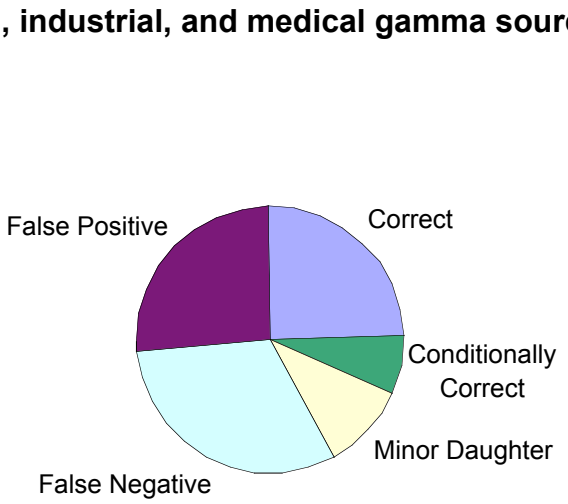

Fig. 9. Breakout of the remaining identification results (representing 310 measurements) that are not represented in Figures 7 or 8. These include SNM, industrial gamma sources, and nuclear medicine gamma sources.

SUMMARY

We have found the intrinsic efficiencies of the detectors examined in this study to be quite similar, suggesting the differences in absolute efficiency can be attributed to crystal size. We have also

found the resolution profiles of the detectors to be very similar for the NaI and CsI detectors. Classifying an instrument's identification of the radioisotope responsible for a gamma spectrum is complicated and categories to perform such a classification are presented. As a group, the instruments included in this study performed quite poorly in identifying radioisotopes. One of the contributing factors to this poor performance may be due to calibration drift. Work is needed to improve both calibration stability and isotope identification algorithms.

REFERENCES

[1] J. M. Blackadar, J. A. Bounds, P. A. Hypes, D. J. Mercer, and C. J. Sullivan, "Evaluation of Handheld Isotope Identifiers," Los Alamos National Laboratory, Los Alamos, NM, LA-UR-03-2742, April 2003.

[2] E. Browne and R. B. Firestone, "Table of Radioactive Isotopes," McGraw-Hill, Inc., New York, 1986; W.K. Hensley, Synth Program version 5.1, December 1998; and references therein.

[3] H. Dockery, "Developing Standards for Nuclear Detection/Decontamination Equipment and Systems," Presented at 5th Annual SW Chapter INMM Meeting, Taos NM, May 1, 2003.

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