

Performance of a portable HPGe-based Nuclide Identifier on Multiple Nuclide Mixtures

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Abstract

An important part of the Homeland Security defense against illicit nuclear trafficking is the ability to identify the specific nuclides causing a radiation portal alarm in order to differentiate between innocent radionuclides and controlled radionuclides. After a portal monitor has detected radiation emanating from a person, a package or a vehicle, the usual next step is to employ a Handheld Radio-Isotope Identifier (HHRID) to identify the source of the radiation by gamma-spectroscopic means. For a HHRID to be useful, it must yield a low number of false positives (reporting a nuclide that is not present) and an even lower number of false negatives (not reporting a nuclide that is present). The ANSI N42.34 standard specifies more than 20 individual nuclides to be identified and a ^{133}Ba with Pu mixture. In the IAEA specification¹ for Hand Held Radioisotope Identifier 4 additional nuclide mixtures are listed which must be accurately identified.

The Detective is a HHRID based on a HPGe detector cooled by a small mechanical cooler. The HPGe detector is comparable in efficiency to existing NaI-based instruments, but, due to its very much higher resolution, is considerably more sensitive and effective at identifying the source of the radioactivity. The spectrum analysis is performed in the internal microprocessor and reported on the built-in display. Because of the excellent resolution of the HPGe detector, good separation of the gamma-ray peaks used in the nuclide identification is achieved. The Detective has been tested with the mixtures given in the ANSI standard and IAEA specifications as well as other mixtures over a range of counting times and shielding conditions. Results will be presented that show the accuracy of the result with respect to false positives and false negatives. The real-time analysis algorithm will be shown to report results in a fraction of the time required by both the ANSI and IAEA standards.

Introduction

An important part of the Home Land Security defense against illicit nuclear trafficking is the ability to detect radionuclides passing a control point and then to identify the nuclides detected. For any identification system to be useful, it must make rapid determinations, have a low number of false positives (reporting a nuclide that is not present) and an even lower number of false negatives (not reporting a nuclide that is present). While this is important for single nuclides, it is even more important for mixtures of nuclides. That is, the identification system must be able to report the presence of certain nuclides in every case and especially in the case where there are other nuclides in the sample (mixtures).

The ANSI N42.34 standard and the IAEA draft specification¹ give some mixtures of nuclides

¹Co-ordinated Research Project: "Improvement of Technical Measures to Detect and Respond to Illicit Trafficking of Nuclear and other Radioactive Materials," Technical / Functional Specifications for Border Radiation Monitoring Equipment

with which to test the performance of a HHRID to assess the quality of the instrument. The HHRID must be able to identify all the components of the mixture within a certain time. The requirements include correct identification of both unshielded and shielded sources.

The mixtures specified are plutonium with ^{133}Ba , uranium with ^{57}Co and U with ^{137}Cs . These mixtures were chosen because the overlap of the gamma ray energies of the components makes it difficult to determine the components, that is, in these mixtures it is easy to mask the plutonium or uranium with the other nuclides chosen. They therefore represent potential illicit trafficking concealment scenarios

The ORTEC Detective is a small, self-contained, portable HHRID, based on a HPGe detector. The detector is cooled by a high reliability Sterling cooler operated by batteries. The spectra are collected and analyzed in an internal MCA. The MCA is a DSP type with 8k channel resolution. The detected nuclides and nuclide type are shown on the built in display. The list of important nuclides and nuclide types are defined in the standards.



Figure 1 Detective HHRID Device.

Methods

In every case, the sources were placed in front of the Detective directly in line with the center of the endcap such that the dose rate at the detector is 500 nSv/hr from each of the nuclides in the mixture, taken individually. For the shielded samples, the dose rate, measured at the detector, was also 500 nSv/hr, in compliance with IAEA procedures. This required reducing the detector-to-sample distance when source shielding was present.

The standards specify a time-limit for data acquisition, analysis and the reporting of the identification of the radionuclide(s). The Detective operates in a real-time mode, where the spectrum is continuously accumulated. The accumulating spectrum is re-analyzed as quickly as possible without stopping the acquisition. The identified nuclides are displayed as either “suspected” or “found”, by type (e.g., “NORM”, “MEDICAL”, “INDUSTRIAL”, “NUCLEAR”). In addition, all classification of nuclides can be reported by nuclide name. In the case of nuclear material (SNM), the instrument will identify a subclassification for U and for Pu, in terms of “DU”, “UNAT”, “LEU”, “HEU” and of “WGpu” and “RGpu” respectively. This identification can be as quick as a second or two for a single unshielded nuclide at a dose rate of 500 nSv/hr. The boundary in the Detective between LEU and HEU is chosen to be about 30% enrichment.

Four enrichments of plutonium were available: 63%, 74%, 84% and 93%. Nine enrichments for uranium were available: 0.3%, 0.7%, 1.9%, 2.4%, 4.4%, 20%, 54%, 90%, and 93%. Not all tests were done on all enrichments of uranium. All materials are traceable standards.

The following tests were made: 1) time to identify plutonium and to specify as reactor or weapons grade plutonium with ^{133}Ba ; 2) minimum ratio of plutonium to barium identified in the allowed analysis time; 3) time to identify uranium and to specify as depleted, natural, LEU or HEU with ^{137}Cs ; 4) time to identify uranium and to specify as depleted, natural, LEU or HEU with ^{57}Co ; 5)

minimum ratio of U to ^{137}Cs identified in the allowed analysis time; 6) minimum ratio of U to ^{57}Co identified in the allowed analysis time. The plutonium was tested with no shield, and one or more of these shields: 5 mm steel, 1 mm cadmium, 10 mm lead.

A typical plutonium spectrum is shown in Fig. 3. A typical uranium spectrum is shown in Fig. 2.

Results

Plutonium and ^{133}Ba

The time to identify that the sample contained plutonium is less than 60 seconds for all enrichments, as shown in Fig. 4. For the higher enrichments, the time is less than 30 seconds. The maximum time specified in the various requirements is 120 seconds for unshielded or shielded by 5 mm of steel and 300 seconds when shielded by 10 mm lead.

The time to identify the grade as reactor or weapons is less than 200 seconds for all cases except the steel shielded 63% enrichment sample. Note that adding shielding usually

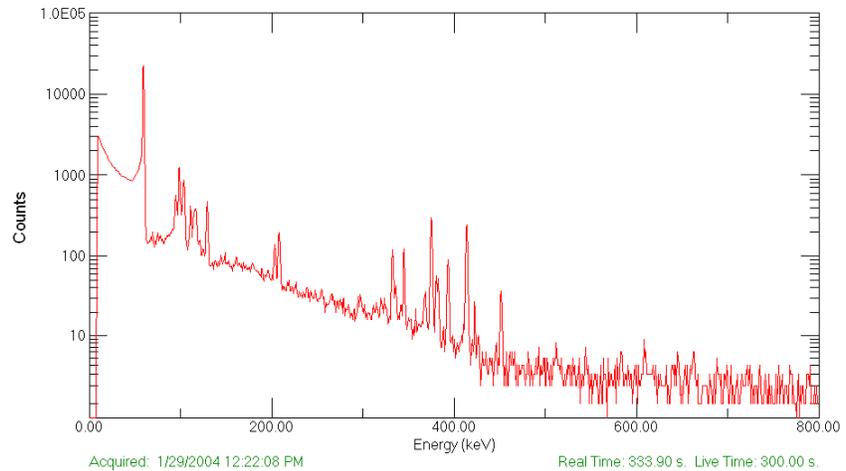


Figure 2 Typical Plutonium Spectrum.

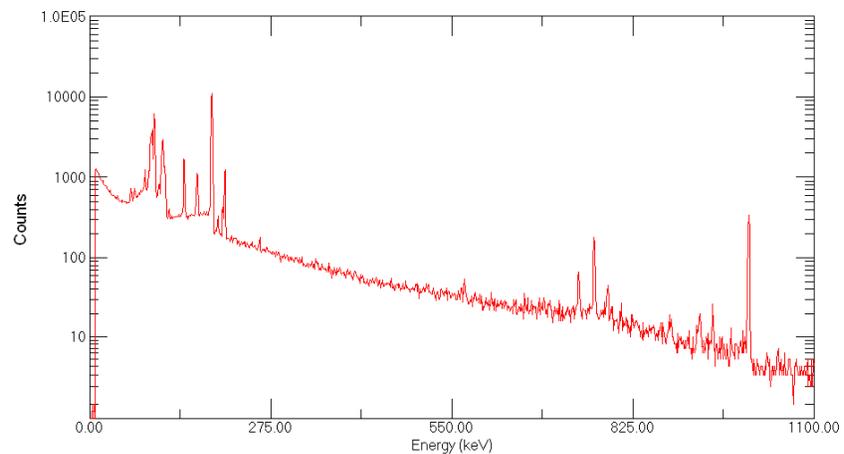


Figure 3 Typical Uranium Spectrum.

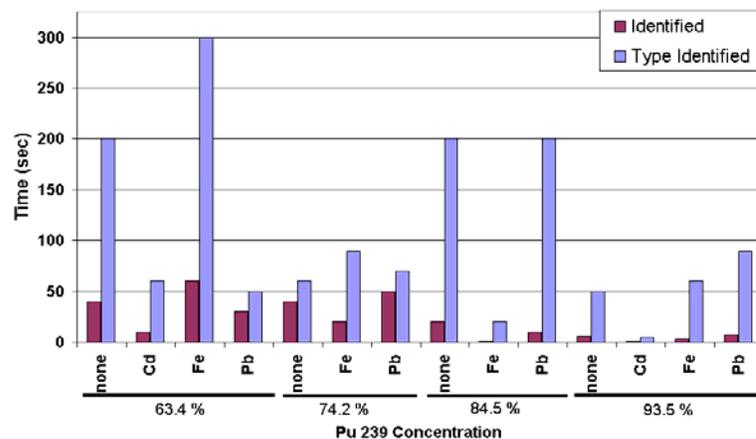


Figure 4 Time to Identify Unshielded Plutonium and ^{133}Ba .

reduces the time needed to make the identification. It is believed this is due to the high ^{241}Am content contributing to the measured dose, but not to the plutonium content of the spectrum. The shielding will remove most of the ^{241}Am , requiring a higher number of plutonium gamma rays to yield the required dose.

The amount of plutonium that can be detected in a situation with a ^{133}Ba dose of 500 nSv is less than 220 nSv, as shown in Fig. 5. That is, plutonium can be identified when it is less than half the dose of ^{133}Ba . The reactor or weapons specification requires equal doses in many cases.

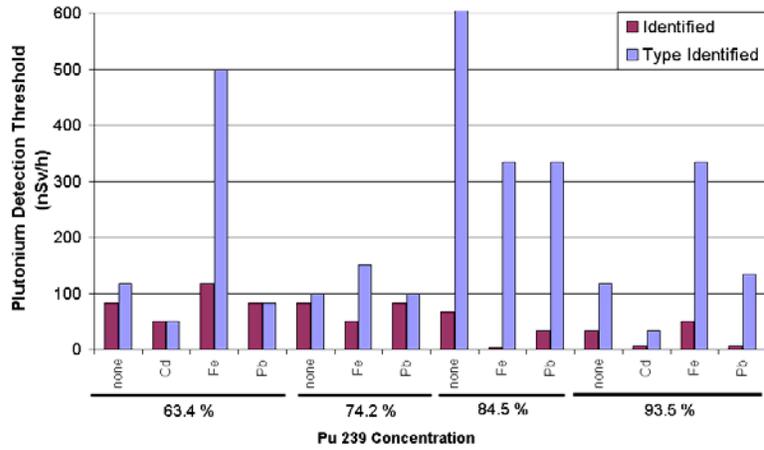


Figure 5 Plutonium Threshold with ^{133}Ba in 300 sec.

Uranium and ^{137}Cs or ^{57}Co

The time to identify uranium in the sample is less than 4 seconds for all enrichments, except steel-shielded depleted uranium, as shown in Fig. 6 and expanded in Fig. 7. The type (depleted, natural, LEU or HEU) is identified in all cases except depleted and natural.

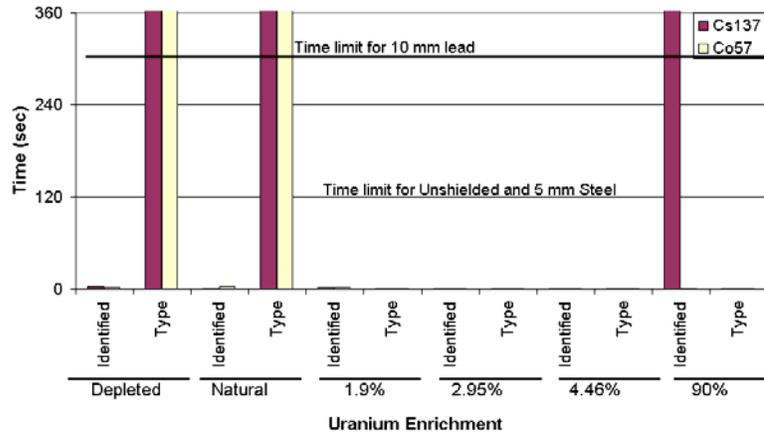


Figure 6 Time to Report Uranium for Various Enrichments.

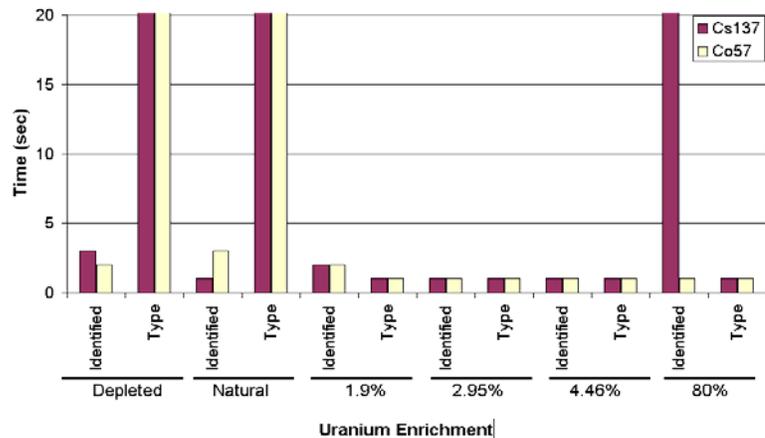


Figure 7 Expanded Time to Detect for Uranium with Mask.

The minimum amount of uranium that can be detected in 2 minutes counting time with 500 nSv of ^{137}Cs is about 350 nSv for 90% enrichment. For many enrichments, the minimum amount is less than 50 nSv as shown in Fig. 8.

Summary

Based on these tests, which follow the guidelines, the instrument performed as follows.

In all cases, the mixture consists of 500 nSv/h of the "mask" nuclide, added to the specified quantity of uranium or plutonium. The "dose-ratio threshold" is defined to be the standard 500 nSv/h dose rate from the mask in ratio to the smallest dose rate from uranium or plutonium detected in the time stated.

For unshielded uranium mixtures, with uranium at 500 nSv/h in the presence of ^{137}Cs or ^{57}Co mask, the time to identify as uranium is less than 5 sec. For LEU and HEU samples, the enrichment is also reported in less than 5 sec.

The uranium dose-ratio threshold for a 60 second measurement in the presence of ^{137}Cs or ^{57}Co mask is greater than 7:1 for identification as uranium for unshielded samples, greater than 3:1 when shielded with 5 mm of steel. To report the enrichment, the ratio must be greater than 2:1 for unshielded, and greater than 1.5:1 when shielded with 5 mm of steel.

For plutonium at 500 nSv/h in the presence of ^{133}Ba mask, the time to identify as plutonium is less than 60 sec, when unshielded or shielded by 5 mm of steel or 10 mm of lead. The type is reported as RG Pu or WG Pu in less than 300 sec.

The plutonium dose-ratio threshold for a 5 minute measurement in the presence of ^{133}Ba mask, is less than 6:1 for identification as Pu when unshielded, less than 4:1 when shielded by 5 mm of steel or 10 mm of lead, less than 1:1 for reporting as WG Pu or RG Pu when unshielded or shielded by 5 mm of steel or 10 mm of lead (with cadmium filter if there is a high americium content).

Conclusion

The Detective handheld radioisotope identifier (HHRID) is able to identify uranium and plutonium in mixtures of masking nuclides under the conditions specified in the ANSI N42.34 standard and the ITRAP specifications in much less time than required. The increased performance is due to the use of HPGe detector and special analysis methods. In addition, it was shown that the Detective can detect special nuclear materials in lower concentrations (compared to the masking nuclide) than required by the standards.

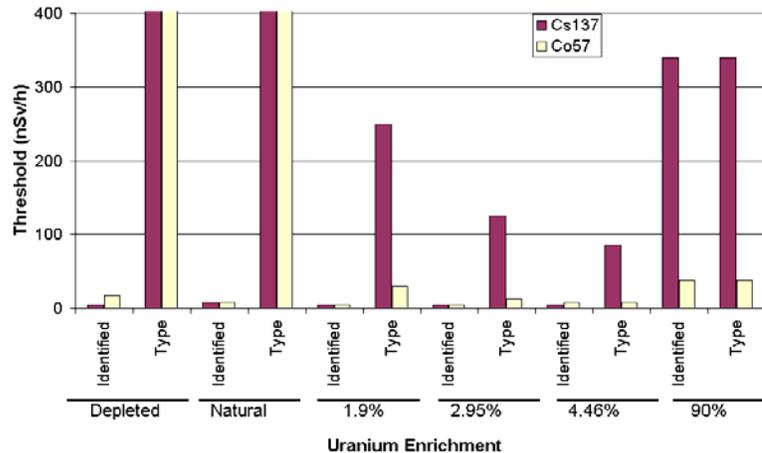


Figure 8 Detection Threshold for Uranium with Mask in 2 minutes.