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High Resolution Detection Systems for Interdiction of Nuclear Material Trafficking

Abstract

The interdiction of nuclear materials during illegal transportation requires both detection of radiation and identification of radionuclides in order to distinguish among the various categories of nuclides and their implied threat. Interdiction regimes, based upon available technologies, were developed rapidly after the tragic events of 9-11.

In general, a low resolution or "no-resolution" portal monitor, based on scintillators, provides initial detection, followed by a search and identify phase. A major problem with these systems is that of innocent alarms or false positives, where, for example, a naturally radioactive substance triggers a portal monitor. An equally severe problem is false negatives whereby nuclear material can be masked or hidden in an otherwise innocent shipment.

Recent experience has shown that in general, 90% of innocent alarms at airports are due to medical isotopes in the bodies of travellers, while in cargo freight, the major problem is caused by natural emitters.

Ultimately reliable nuclide identification must be made. For logistical reasons, such as to preserve traffic flows, it is necessary to make a positive identification in as short a time as possible.

Germanium detectors (HPGe) have been the choice for high-resolution, gamma-ray spectroscopy for many years because of their high resolution and efficiency or stopping power especially at energies above 2 MeV. These detectors are considerably less vulnerable to the problems of false negatives and positives, and are able to identify nuclides with a high degree of certainty.

A new portable nuclide identifier based upon the latest HPGe technology will be described.

Introduction

In the "post 9-11" era, increasing focus has been placed on practical measures to prevent the illicit trafficking of nuclear materials.

The threat scenarios are that radioactive material may be trafficked in order to manufacture a crude nuclear weapon, or that material may be used to manufacture a radiation dispersal device, (RDD or "Dirty Bomb"). While the former would potentially cause widespread destruction, the latter could cause large-scale panic and disruption.

The nuclides are required to create an effective nuclear bomb are well known, and any high school physics course contains the relevant information. Certain non-fissionable radionuclides are better than others for the construction of a dirty bomb, because of their availability, half-lives, chemical and dispersal characteristics.

There are many thousands of so called "orphan sources" which have been lost or discarded from industrial or medical use without appropriate controls, which potentially could find their way into RDD’s.

In general, a low resolution or "no-resolution" portal monitor, based on an inorganic or organic scintillator, provides initial detection, followed by a search and identify phase. A major problem with these systems is that of false alarms, where, for example, a naturally radioactive substance triggers a portal monitor. There are actually two types of "false alarms;" false positives are not the same thing as innocent alarms, but the disruptive affect is similar. A false positive is the misidentification of a benign nuclide as being one which represents a threat, whereas an innocent alarm is caused by elevated radiation levels from legal radioactive materials.

An equally severe problem is false negatives whereby nuclear material can be masked or hidden in an otherwise innocent shipment.

Recent experience has shown that in general, 90% of innocent alarms at airports are due to medical isotopes in the bodies of travelers, while in cargo freight, the major problem is caused by natural emitters. In both cases, although there are "innocent" nuclides present, it is necessary to be sure that no other more sinister radioactive isotopes are being concealed.

The cost of closing a single freight terminal at the port of New York has been estimated to be $500,000 per hour. On the other hand, even crude nuclear devices are capable of 1.0-kiloton explosions, enough to destroy Washington, D.C. or any other major U.S. city. Of 181 confirmed illicit trafficking incidents reported by the IAEA, 17 involved either highly enriched uranium or plutonium. The implications are chilling and the measurements are difficult.

It is therefore of high importance to be able to identify with certainty the radionuclide(s) giving rise to an alarm at a portal monitor or which triggers the radiation pager worn on the belt of a customs agent at a border crossing.

Improved instrumentation for the interdiction of illicit nuclear materials at border crossings, airports and similar transit points is therefore receiving intense interest.

Schemes for Interdiction and Detection Technologies

The current schemes for interdiction are based to some extent on the state-of-art of available instruments.

Figure 1[1] shows the general form of the interdiction process.

Common to this and all other schemes is the three-step approach:

- **DETECT**: The radiation portal monitor or personal radiation detector **DETECTS** the presence of radiation.
- **LOCATE**: The hand-held search instrument **LOCATES** the source of the radiation.
- **IDENTIFY**: The nuclide identification instrument **IDENTIFIES** the nuclide emitting the radiation.

The three-step approach is dictated somewhat by the limited performance of available instruments. This approach is required in order to achieve a solution in which both false negatives (non-detection) and false alarms are at an acceptably low level.

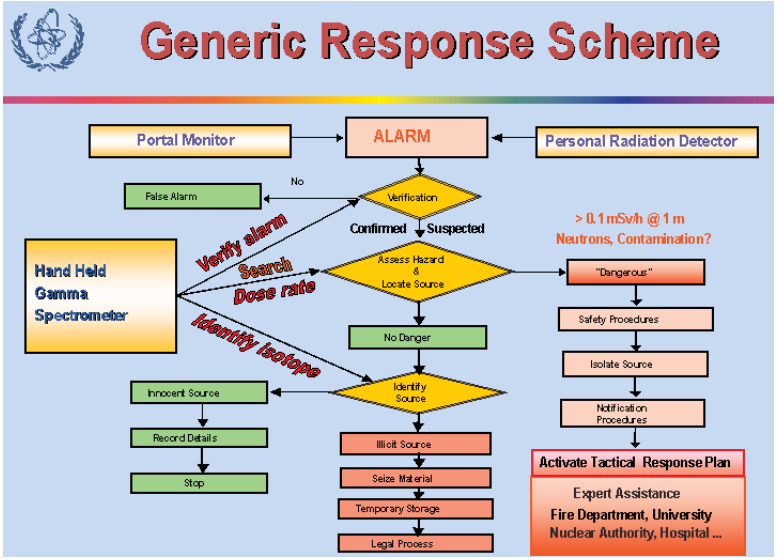

Figure 1. IAEA Generic Response Scheme.

Radionuclides of Interest

Various groups of experts have developed a list of nuclides and classifications which should be unequivocally identified by systems developed to prevent illicit trafficking. The list below, from IAEA is typical.

(1) Nuclear materials: ^{233}U, ^{235}U, ^{237}Np, ^{239}Pu ^{252}Cf
(2) Medical radioisotopes: ^{18}F, ^{67}Ga, ^{99m}Tc, ^{111}In, ^{123}I, ^{125}I, ^{131}I, ^{133}Xe, ^{201}Tl
(3) Industrial radioisotopes: ^{57}Co, ^{60}Co, ^{133}Ba, ^{137}Cs, ^{192}Ir, ^{241}Am, ^{75}Se
(4) Naturally occurring radioactive materials (NORM): ^{40}K, ^{226}Ra, ^{232}Th, ^{238}U

Examples of common substances, which can produce innocent alarms, are:

Potassium nitrate fertilizers	Granite or marble
Vegetable produce	Camera lenses
Thoriated tungsten welding rods	Lantern mantles
Porcelain bathroom fixtures	Ceramic tile
Kitty litter	Medical isotopes

In the ITRAP[2] study two years ago, it was concluded that none of the available hand-held identifiers was adequate for this purpose. NaI based identifiers had good efficiency but inadequate resolution. Room temperature semiconductors such as CZT, have adequate resolution, but low efficiency.

High Resolution HPGe Detectors

Apart from the need for cryogenic cooling, HPGe is the ideal detector material candidate for this application.

High Purity Germanium (HPGe) Detectors have been used for more than 40 years for high-resolution gamma-ray measurements. They have extremely good energy resolution, but are often smaller and therefore less efficient than plastic or NaI detectors to which they may be compared. However, it can be shown[3] that the sensitivity varies linearly with efficiency and is proportional to the square root of the resolution. HPGe detectors have resolution around 30 to 40 times better than NaI, and so gain a sensitivity factor of 5 to 6, often more than offsetting losses due to smaller efficiency.

The potential sensitivity gain from the use of HPGe detector systems is illustrated graphically in Figure 2.

The dominant isotope is medical radioiodine, but the blue spectrum from a detector with poor resolution (selectivity) gives no evidence of the presence of the plutonium which shows up at high resolution. With a low-resolution NaI detector, it is possible to miss a nuclear material such as plutonium, because of the presence of an innocent isotope such as medical iodine. Intermediate-resolution detectors such as CZT cannot solve the problem because their small size and low efficiency make them impractical because of the unreasonably long measurement times to "clear" a suspect case. Moreover their inferior resolution to HPGe means they are still more easily "fooled" than a HPGe detector.

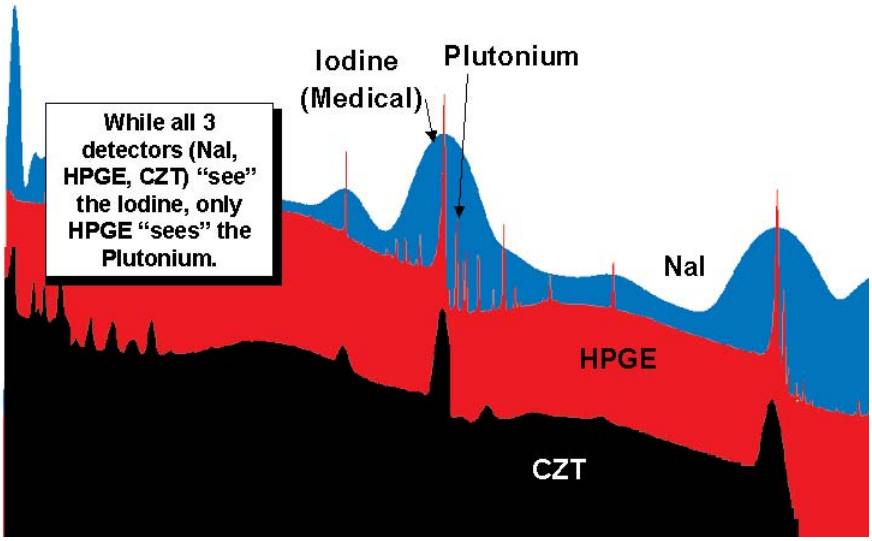

Figure 2. HPGe in comparison to NaI and CZT detectors.

The Detective Portable Nuclide Identifier

It is clear from the foregoing that except for the additional complication of cryogenic cooling, a portable identifier based on HPGe detector technology offers the best chance of minimizing both false negatives and false positives, and of preserving traffic flows at critical border crossings and freight ports.

The ORTEC Detective, which addresses these needs, is a complete, portable nuclide identifier with both gamma ray and neutron detection capability.

The Detective provides several functions.

The primary gamma-ray detector is a small HPGe crystal cooled by a miniature Stirling cycle cooler. An all-digital MCA system processes the data from the detector.

A SEARCH mode is provided for the location of radioactive sources, with a graphical display of activity, and audio alert using an external earpiece or internal "clicker."

Figure 3. ORTEC Detective .

In IDENTIFY mode, a proprietary scheme[7] of identification and classification of radionuclides is used to categorize the nuclides found as Industrial, Medical, Natural, Nuclear, or "Unknown." These classifications are based on an internal, fixed library according to ANSI N42.35.

Gamma Dose Rate is monitored by an internal compensated GM tube. The dose rate is displayed at all times.

Overall, dimensions (including handle, Ge detector endcap and shock absorbers) are 37 cm L x 32 cm H x 16 cm W, and weight is approximately 21 lb (9.5 kg).

The Detective is supplied factory pre-calibrated and adjusted. A re-calibration function allows correct performance to be verified and fine-tuned using the small Cs-137 source.

A sister product designated the "Detective-EX" will provide neutron detection capability also.

The HPGe Detector

A major technical challenge in the development of the Detective was the mechanically cooled HPGe detector. A small ORTEC HPGe detector cooled by a high reliability Stirling cooler (SAX101) from Hymatic Engineering was constructed. The cooler is capable of approximately 1 W of heat lift at 100°K, and draws less than 25 watts when operating. The crystal size chosen was a GEM (P-type) 50 mm diameter by 30 mm deep coaxial crystal. This size was chosen because it is easily cooled by the SAX101 even in high ambient conditions and has single nuclide sensitivity comparable to the NaI detectors in common use for hand-held identifiers.

A potential problem of mechanical coolers is vibration, which causes microphonic noise on the detector output signal, and degrades the peak resolution. Careful mechanical design in the Detective helped reduce the noise, and active methods have been developed to compensate or remove the remaining noise contribution to the output signal. An active digital noise reduction filter (LFR) was implemented in the digital spectrometer section of the instrument.[4]

Figure 4 shows a prototype detector-cooler assembly.

Coolers of this type have been shown to have lifetimes in excess of 50,000 hours. The operational philosophy of the Detective is to keep it running continuously. The battery lifetime of the instrument when cold is ~2 hours, extendible via the use of a battery belt worn by the operator. When not in use, the instrument is held ready by connection to a "docking station," which includes a small Cs-137 check source to ensure the instrument remains fully ready for operation.

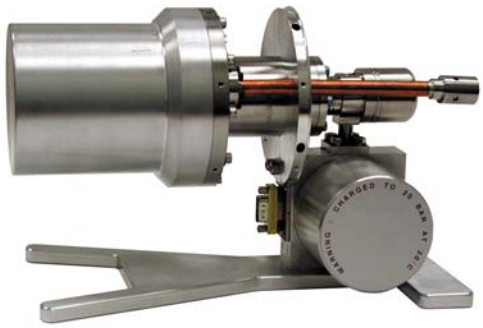

Figure 4. Prototype Cooler Assembly.

Nuclide Identification

As can be seen in Figure 2, the spectrum from a HPGe detector is much "sharper" than that from any other type of radiation detector. That does not mean, however that the false positive/false negative problem is instantly solved. A sophisticated and proprietary identification algorithm which is part of an exclusive licensing agreement with Lawrence Livermore Laboratory[7] is used.

The Detective In Use

Figure 5 shows the operator keypad. Dedicated buttons are provided to simplify the functions of search and identify.

Figure 5.

Figure 6 shows the main operator screen. Gamma count rate and dose rate are displayed continuously, numerically and in bar graph form. The battery life remaining is also displayed.

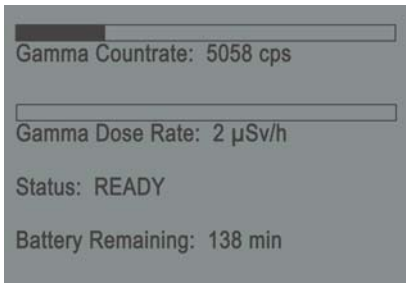

Figure 6. Main Display.

When the search button is pressed the Display in Figure 7 appears. This consists of a scrolling "strip chart" display of total count-rate versus time, in order to facilitate search operations. Instantaneous count rate and dose rate are also displayed.

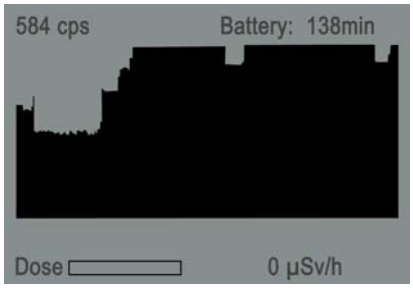

Figure 7. Search Mode Display.

When the Identify button is pressed, a screen like Figure 8 appears. In this example, one industrial and one natural isotope have been identified, and the count rate has been determined to be low enough that with more time, other nuclides might be identified.

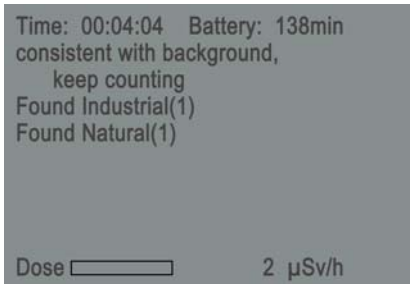

Figure 8. Identify Screen.

A single button push takes the operator from the identify screen of Figure 9 to the screen in Figure 10 where the identity of the found nuclides is listed. All of the nuclides in ANSI 42.35 are in the identification library.

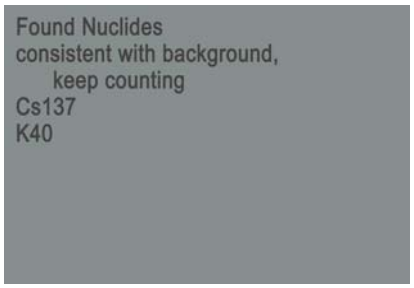

Figure 9. Found Nuclides Display.

If desired, the user can display the actual radionuclide spectrum, and manipulate the screen display vertical scale, zoom, etc., like a conventional multichannel analyzer. (Figure 10.)

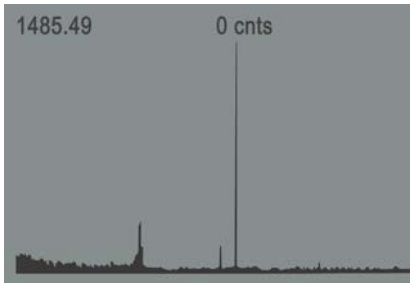

Figure 10. Spectrum Display.

Calibration Check

The Detective is supplied factory pre-calibrated. A very simple procedure has been developed to verify and if necessary update the factory calibration. A small Cs-137 source is used, which can be installed in the docking station for use while recharging if required. The calibration check procedure is shown in Figures 11, 12, and 13.

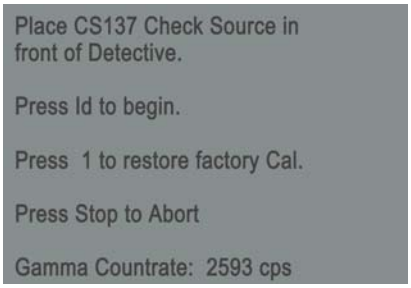

Figure 11.

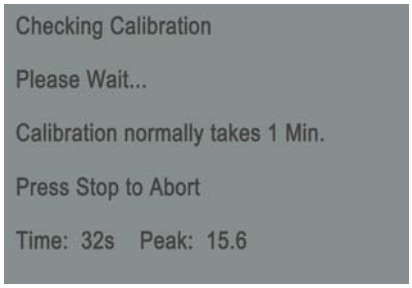

Figure 12.

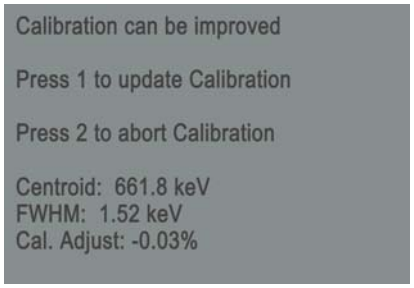

Figure 13.

Instrument Performance

An interesting insight into the anticipated performance for SINGLE nuclides can be drawn from Figure 14.

The figure shows comparative data from seven portable nuclide identifier systems taken from Reference 5 and the Detective. The Detective is the only instrument employing HPGe. Other than the Detective, all the other instruments employed NaI or CZT as the detector type. The instruments are identified in Reference 5.

The X-axis in the figure is energy and the Y-axis is the quantity Efficiency/SQRT (Resolution) measured under similar conditions for each instrument. This quantity is a "figure of merit" relating to the detection limit of each instrument for a single nuclide. It therefore represents the speed with which a positive identification may be made, and by implication represents the reliability of that identification.

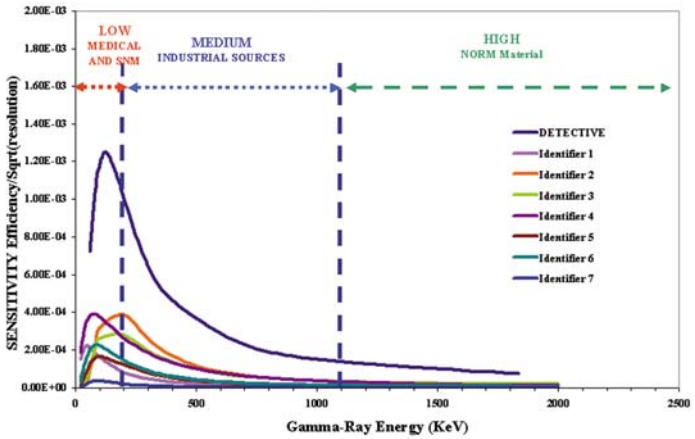

Figure 14. Sensitivity for a Single Nuclide, Identifiers Compared.

The energy regions marked as LOW, MEDIUM and HIGH are taken from Reference 6. It is clear from the "sharp" spectrum of Figure 2 which represents a medical-plutonium mixture and the relative sensitivities shown in Figure 14 that the Detective would be expected to show vastly superior sensitivity and resistance to innocent alarms, false positives and false negatives in comparison to all other hand held nuclide identifiers.

The Detective will soon be performance tested by both the National Assessment Group in the U.S.A. (NAG) and at the IAEA. It will be tested on actual simulated trafficking examples.

Conclusion

False positives and false negatives are a major problem in securing border crossings to radionuclide illicit trafficking activities. HPGe detector technology offers the best hope of eliminating these problems. A portable identifier, incorporating a small mechanical cooler has been developed and has been shown to offer greatly improved performance over low-resolution instruments. Further, more rigorous testing is taking place in the near future.

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2. ITRAP, "Illicit Trafficking Radiation Detection Assessment Program," Final Report, P. Beck, ARC Seibersdorf, February, 2001.
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7. Lawrence Livermore National Laboratory License Agreement TL-01753-03 (hardware) and TL-01754-03 (software).

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