Hand-held Radio Isotope Identifiers for Detection and Identification of Illicit Nuclear Materials Trafficking: Pushing the Performance Envelope.

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Abstract

In the 3 years that has elapsed since the events of 9-11, a whole class of radiation measurement instrumentation has evolved to address the threats of nuclear terrorism; namely the hand-held radioisotope identifier or "HHRID" (sometimes called simply a "RID"). The purpose of the HHRIID is to provide an easy-to-use and reliable means of identification of radioactive material when encountered by customs and security agents at airports, ports and boarder crossings. This activity can be in people, vehicles, and shipments. An ideal instrument will obtain an unequivocally correct identification with no false positives or negatives in a short period of time, and clearly indicate the presence of any illicit material, whether shielded or "masked" by other "innocent" radionuclides. The complication in the detection is the large number of innocent radionuclides in transport.

The first instruments used for interdiction were mainly "Health Physics Instruments". Typically these are "dose" instruments and not nuclide specific. As these instruments were used, it became clear that the performance varied widely. To ensure a uniform ability in the instruments, a regime of independent testing [1,2] has evolved along with standard(s) [3,4] that define minimum levels of performance. Most of today's instruments meet these minimum requirements and the standards are under review to see if they can reasonably be tightened. It is interesting to note that about 10 years ago, the Russian Customs Office implemented a radiation inspection system, not for illicit trafficking, but for payment of duties.

This paper reviews some recent performance data from a state of the art HHRIID in comparison to the current accepted performance standards.

Introduction

The consequences and costs of false negatives and false positives occurring at border crossings and other traffic pinch points has been well documented. Shutting down the Port of New York for one hour because of a false alarm has been estimated to potentially cost $500 million. In the case of a "dirty bomb" (radiological dispersion device or RDD), the greatest hazard would be from the effects of the conventional explosives (if present). The widespread radioactive contamination could have a large psychological and financial impact. It has been estimated that if an RDD was set off in the heart of Washington or New York City, the economic effects might reach $40 billion. Similar effects might be achieved by simple contamination of a water supply or a large air conditioning system using commonly available materials. The detonation of an actual nuclear device, either an improvised nuclear device (IND) or a small military device in a city would have huge economic impact and loss of life.

It is therefore of extreme importance that people, packages, and vehicles are monitored for illicit radioactivity at transit points. However, while the detection of radioactive material is of great value in the prevention of a terrorist attack, unless the incident is quickly and accurately resolved, there will be a high number of problematic “hits” or detections at primary portals to be investigated. The consequential cost of disruptions due to false alarms or innocent alarms is likely to cause pressure which may lead to the more dangerous false negative situation where illicit material is classed as innocent in the rush to “keep the wheels of commerce turning”.

Review of Radioactivity Types : “Natural”, “Medical”, “Nuclear” and “Industrial”

Radioactive material is usually classified as belonging to one of four types, or being a mixture of types.

Natural radioactivity (NORM) is the term used to describe the radioactivity present in many everyday materials, including human beings! Common examples are ceramic tiles, welding rods, used well-drilling equipment, fertilizer, kitty litter, yellow glass, and other mineral-based objects. Although not concentrated, natural radioactivity can be a problem because of the large quantity of material. A single shipment could be hundreds of tonnes. Presence of natural radioactivity can confuse a detection system into making a false determination; negative or positive.

Medical radioactivity refers to the kinds of radioactive sources used for any medical treatment or diagnostic procedure. Medical isotopes are usually short lived, that is, they decay to harmless nuclides in a short time, but they are initially highly concentrated in a person or shipment, and once again could confuse a measureent system.

Nuclear refers to “SNM” or special nuclear material, and includes all of sources used by the weapons manufacturing or research establishments. SNM is a special situation and is treated very seriously.

The Industrial category includes nuclides used for gaging, radiography, well logging and other uses. Industrial sources are a danger because of the high activity and potential availability. They could be used in an RDD.

The discrimination between innocent and illicit radioactive materials is basically a physics problem. The goal of any interdiction regime is to quickly determine if a suspicious person, container or vehicle may contain a material of interest to a terrorist. Fortunately, all radioactive materials have a natural signature and constantly emit gamma rays, X-rays, or neutrons. Neutrons are more likely in the case of SNM used to make uranium or plutonium nuclear weapons. The signatures are like "fingerprints"; the gamma-ray energies are unique for the material and may be used to identify it. The job of the radiation detector, therefore, is to identify the fingerprint of the one or more radioactive materials which are present, shielded or unshielded.

Radiation Detectors Fall into Two Categories: Gross Counters and Spectroscopic

Gross counters register each gamma-ray or neutron emission in the same manner regardless of energy. Examples are Radiation Vehicle Portal Monitors and Radiation Pagers, now being deployed at border crossings, seaports, airports, and with law enforcement personnel. These gross counters are useful for screening people, packages, luggage, cargo, and vehicles for the presence of gamma or neutron radiation. They have no identification capability because they have no energy discrimination or "resolution". Natural and medical isotopes result in a large problem due to innocent alarms. Typically, a gross counter is constructed using "plastic scintillators". Some attempts have been made to make these systems less resistant to false alarms via so-called "NORM Suppression" algorithms[5], but the problem is that reducing false positives increases the likelihood of false negatives. It is a real-world limitation caused by the lack of energy resolution.

Spectroscopic detectors are able to discriminate one kind of radioactive material from another by analysis of the gamma-ray energy fingerprint. Low resolution spectroscopic detectors include sodium iodide (NaI) and cadmium zinc telluride (CZT) detectors, which can operate at room temperature. Sodium Iodide detectors are the most commonly used in HHRIIDs at present. CZT is considered impractical because only small detectors are available. CZT has reasonably good energy discrimination, or resolution, better in fact than sodium iodide, but the small size means lack of overall sensitivity for search operations.

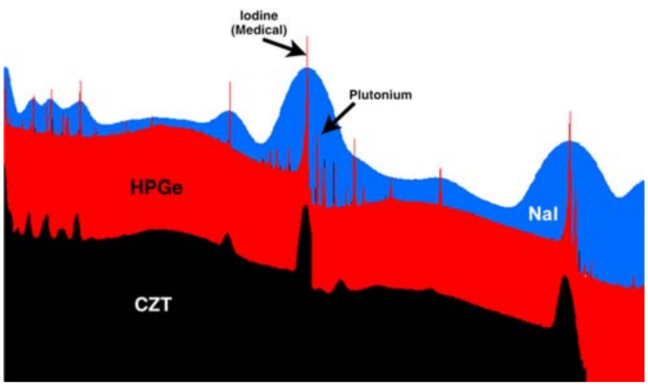

Figure 1

A class of spectroscopic detector called high purity germanium or "HPGe" offers the best of both worlds: High sensitivity combined with the best energy resolution or "fingerprint determination capability". To achieve this performance, this class of semiconductor detector needs to be operated at cryogenic temperatures. Recent developments have made this practical.

Figure 1 shows a "spectrum" of radioactive materials in combination measured with three spectroscopic detector types. Blue is sodium iodide, red is high purity germanium and black is cadmium zinc telluride. The horizontal axis represents gamma ray energy and the vertical axis is the number of "hits" on the detector at a given energy.

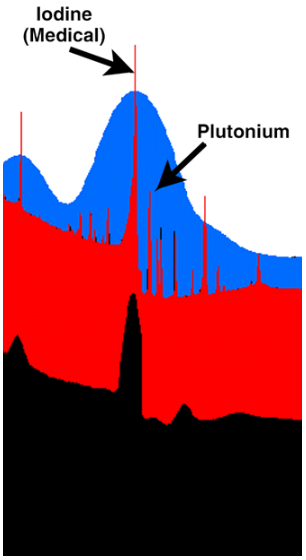

Figure 2

Figure 2 shows an expanded part of the previous figure. Extra "spikes" or peaks are clearly identifiable in the red spectrum which are not easily seen in the other two. These peaks are due to the presence of plutonium mixed with an innocent medical nuclide, radioactive iodine. This figure illustrates that it would be much simpler to make a "smart instrument"able to correctly identify all nuclides present by using a germanium detector than either of the other two types.

There are a number of HHRIID instruments currently in use based on sodium iodide. They have undergone various independent tests, beginning in 2001. These tests showed they provide adequate (and improving) performance in simple scenarios such as single, unshielded radioactive sources. Performance standards were made and have been published (ANSI N42.34 and IAEA test standards) to quantify the performance. These basically define levels which must be reached in order for an instrument to be even considered for use at an inspection point. An accreditation (ITRAP testing) was also carried out in 2001 on the instruments available at that time. Of course, an illicit trafficker will be constantly trying to defeat detection of a clandestine shipment by shielding and mixing the illicit nuclide with other radioactive material. In acknowledgment of this, the instrument performance testing carried out today is increasingly stringent, and the instruments are improving in performance.

High Purity Germanium Detector HHRIID: The ORTEC Detective

The most recent arrivals on the HHRIID scene are the ORTEC Detectives. They are unique in that they are based on the high purity germanium technology. The Detective is a gamma-only detector, while the other, the Detective-EX, also detects neutrons. The neutron count is used for confirmatory purposes for SNM. By utilizing the much more "spiky" resolution performance of the germanium spectrum, special software has been developed, internal to the instruments, which allows a sophisticated and certain analysis to be carried out rapidly and at the push of a button. A low-power, miniature Stirling Cycle refrigerator was developed to cool the HPGe detector without liquid nitrogen (LN2).

Figure 3 shows the Detective portable instrument (-EX version).

Figure 3

The performance of the Detective is currently being evaluated by a number of testers. It clearly represents a new realm of performance and resistance to false alarm problems, enabled primarily by the use of the high purity germanium detector technology.

ORTEC's own performance testing[6] has shown that for single radioactive sources of all types specified by the standards, shielded and unshielded, an unequivocal result is typically obtained around 20 to 100 times faster than required by the standard. The higher the enrichment (more dangerous), the faster the detection. The standards contain tests with mixed radioactive sources simulating attempts to divert SNM by masking it with another nuclide. The instrument has proven capable of detection and classification of traces of SNM present at 5 to 10 per cent of the minimum amount dictated by the standard in the time allotted for the measurement.

So far unpublished results from ongoing independent testing by an international organization has led to the following comments (quotes):

- “The Detective can detect heavily shielded Pu better than an NaI detector (sodium iodide) based RIID.”
- “The Detective can detect heavily shielded U better than NaI detector (sodium iodide) based RIID”
- “5 mm lead shielded 80% U can be detected with the Detective, but not with a NaI (sodium iodide) based RIID”.
- “The Detective recognized the Uranium in less than two minutes. The ... (leading sodium Iodide instrument...) was not able to "see" the Uranium at all. The ability to detect HEU (highly enriched uranium), hidden in fertilizer with the Detective is a significant result!”
- “The sensitivity of the Detective with respect to the detection of a masked Pu sample is significantly higher compared to a NaI (sodium iodide) based RIID”
- The Detective is “...the ultimate tool for the identification of shielded sources and nuclear materials, masked by other isotopes. It should be available in the tool kit ... for the quick in-situ resolution of unclear cases, avoiding ... the need ... to open dangerous objects at the border ....”

Conclusion

The introduction of high-purity germanium in instruments for prevention of radiological terrorism represents a substantial increase in performance. These portable instruments can dramatically reduce false alarms and at the same time reduce false negative determinations to a level at which trafficking is no longer realistically possible. “Expert system” software places these important tools in the hands of front-line responders with no loss of performance. Portal monitors based upon this technology promise to transform the movement of freight.

References

1. ITRAP, "Illicit Trafficking Radiation Detection Assessment Program," Final Report, P. Beck, ARC Seibersdorf, February, 2001.

2. "Evaluation of Commercial Detectors," J.M. Blackadar, S.E. Garner, J.A. Bounds, W.H. Casson, D.J. Mercer, INMM 44th Annual Meeting, Phoenix, AZ, July 13-17, 2003.

3. ANSI N42.34-2003 American National Standard Performance Criteria for Hand-held Instruments for the Detection and Identification of Radionuclides Published by The Institute of Electrical and Electronics Engineers, Inc. January 2004.

4. IAEA-TECDOC-XXXX Technical / Functional Specifications for Border Radiation Monitoring Equipment. To be published.

5. "The Application of Gamma-Spectrometric Techniques with Plastic Scintillators for the Suppression of "Innocent Alarms" in Border Monitoring for Nuclear and other Radioactive Materials," K.E.Duftschmid, World Customs Exhibition and Forum, Budapest, Hungary 22-24th Sept, 2003.

6. “Performance of a Portable HPGe-based Nuclide Identifier on Multiple Nuclide Mixtures” R.M. Keyser and T.R. Twomey, presented at 45th INMM Conference Orlando 2004.