

Energy differentiation using multiple sensor integration to maximize efficiency, speed, and cost effectiveness in portable isotope identification systems.

Abstract: Lanthanum Bromide (LaBr) and Cadmium Zinc Telluride (CZT) provide high spectral resolution, but are expensive in crystals large enough to detect medium and high energy photons. Relatively inexpensive Sodium Iodide (NaI) provides excellent medium and high energy bandwidth response, but has medium-to-low energy resolution. By fusing spectroscopy data measured by smaller, less expensive high-resolution crystals with large NaI crystals, the beneficial properties of both can provide unique and automatic spectral identification of over 100 isotopes, with no special radiological identification training required of the operator.

1.0 Introduction

Handheld instrumentation that identifies radioisotopes are primarily treated as scientific instrumentation equipment and not as a basic tools for security personnel to employ. As a result, these isotope identifiers have not been disseminated in large numbers to security forces and have typically been limited to specially trained teams within the larger security forces. The reasons for the slow spread of identifiers into more general use by security forces are many: device complexity; lack of confidence of the security forces to use isotope identifiers effectively; concerns about accepting the cost of performing the isotope identification mission; and concerns over training costs, effectiveness, and the ability of layman to interpret the results.

The evolution of isotope identifiers development has not helped the situation, from the viewpoint of the layman. The technologies applied in isotope identification systems tend to be based on a single primary detector. As each detector has strengths and weaknesses, this leaves the operator to interpret ambiguity and resolve discrepancies in the primary detector's weaknesses. The more problem solving and interpretation the operator has to perform, the greater the training required. The end result is that radiation security has not been addressed to near the level it could be and the isotope identification mission is still left in the hands of specialists.

Single detector systems can provide excellent and unambiguous performance in both detection and identification. However, large single crystal solution for Lanthanum Bromide and Cadmium Zinc Telluride are expensive. The requirements of the security mission can be most efficiently met by sensor fusion between multiple sensor technologies, allowing the strengths of each detector type to correct the weaknesses of the others.

2.0 Mission Requirements of an Isotope Identifier

Determining the best isotope identifier for a specific security mission is difficult for a security organization. Lacking a background in radiation, many security forces seek advice and recommendations from scientific government organizations. These organizations typically have a warranted hard science perspective and frequently lack an in-depth understanding of the mission requirements of security forces that do not contain personnel conversant in radiation physics. Many purchased isotope identifiers are not used to their full capability by security forces simply because they do not meet the mission requirements of the security force. Typically they are too complex, lack intuitive functions to perform basic isotope identification, and can provide ambiguous results.

An isotope identifier has two key roles. It must find the isotope (Detection) and it must identify the isotope (Identification).

2.1 Detection Performance

The greatest challenge isotope identifiers face is detecting isotopes through shielding. It is a simple fact of physics that the Mean Free Path (reduction to a 1/e level) of emitted photon energies gets alarmingly short in dense metals. Effective and optimized detection of radiation must remain a critical function of an isotope identifier. This requires a two-pronged capability of a high-efficiency gamma photon detector and neutron detection capability.

A high efficiency gamma collection detector is required to maximize the number of photons collected. Even through significant shielding, photon levels above the natural background can exist. The lowest cost high-efficiency detector is Sodium Iodide (NaI) doped with Thallium. The low cost of producing large NaI crystals allows for large detectors. The NaI detector is the cornerstone of the majority of commercial isotope identifiers. However, the NaI detector has poor-to-medium energy resolution (dependent on photon energy), making it a weak performer for identifying isotopes.

Neutron detection capability is critical to countering shielding around nuclear weapons. The neutron detector has to be large, sensitive, and surrounded with an integrated moderator. Neutron detectors without an integrated moderator, or that depend on moderation from the human body (i.e. water) are not practical since the technique to maximize gamma detection (holding the detector close to the potential radiation source) and the technique to maximize neutron detection (holding the neutron detector close to the body for moderation) is opposite and almost guarantees misuse.

In summary, the Detection mission requires a highly efficient gamma detector and a large neutron detector with integrated moderator.

2.2 Identification Performance

Identification requirements from government agencies are understandably focused on detecting nuclear weapons (special nuclear materials -SNM) and on naturally occurring radiation materials (NORMs). Nuclear weapons are prioritized due to the incredible threat they represent. NORM is emphasized since they are by far the most common isotopes that will be detected at inspection points. Isotope identifiers that focus solely on SNM and NORM isotopes need only detect several dozen different isotopes.

However, the threat from contamination weapons (such as a dirty bomb) is also highly significant. A true terrorism weapon, a contamination weapon carries low immediate health risk relative to fears of long-term exposure. The economic damage due to a release of radioactive contamination may run in the billions of dollars and deny access to important facilities for months, though the immediate casualty numbers are low to none. Because the threat of contamination weapons is so much lower than nuclear weapons, less emphasis has been spent on identifying those easier to acquire materials that could be used to develop contamination and economic denial type weapons. A contamination weapon released on the stock exchange, a government building, or an airport terminal would potentially shut the facility down for weeks to months.

The mission to identify all potential isotopes that could be used as contamination weapons is much larger than the mission to detect SNM and NORM isotopes. Contamination weapons could be made of any isotope currently available in industry. To meet the mission of identifying any isotope, an isotope identifier must utilize a high resolution (CZT or LaBr) detector. NaI detectors have medium-to-poor resolution, depending on energy, and cannot resolve signatures of many isotopes without considerable prior operator knowledge (such as user selected sub-libraries to narrow the isotopes that can be identified). While CZT has excellent resolution and LaBr almost as good, they are expensive to produce a crystal large enough to collect high-energy photons efficiently.

2.2 Identification Performance (Cont.)

Identification speed is one requirement that has historically been overemphasized as a critical requirement. Speed is dependent on collection volume, detector efficiency, the strength of the isotope, shielding between, and range. The practical difference between a ten second identification and a one minute identification is irrelevant due to the variability of the specific inspection situation. Isotope detection must occur within seconds to ensure that no radioactive package, vehicle, or person can pass through an inspection point without detection. Once detected and diverted from the inspection line, the isotope identification only needs to be performed within minutes. Speed is critical for detection. Accuracy is critical for identification.

2.3 Training

The training requirements of an isotope identifier for use by a security force differ from the requirements of a scientific instrument. Security personnel use many types of equipment and are trained on many devices. An isotope identifier must be extremely easy to use, intuitive, and require little to no training. This is an easy statement to make (indeed, most marketing literature uses similar words), but cannot be overstated. All the excellent performance capabilities of an identifier are useless if it cannot be picked up and used effectively six months after a training course. If a long training course is necessary to operate an isotope identifier, then operation in the field may be problematic when months have passed since the initial training.

To minimize the time required for effective training, the performance of the isotope identifier must require little or no analysis from the operator. The operator should not have to understand histograms, or provide judgment on which category an isotope may belong. Detection measurements should be displayed intuitively and Identification should be clearly provided at the press of a button.

Conversely, the requirement for ease-of-use and minimal training again become a performance requirement. Detection must be performed with an efficient and effective detector and Identification must be done with a high-resolution detector to eliminate ambiguity. An ambiguous or incorrectly identified isotope requires the operator to provide the knowledge to resolve the ambiguity, thus requiring more training.

2.4 Cost

The cost of performing the isotope identification mission is a key element to dissemination of identifiers to more security forces and increasing radiation security overall. The cost of the identifier itself is part of the mission cost, but not the most significant. Far more critical is the cost of training and maintaining personnel effectiveness at performing the mission. The less intuitive the output of an isotope identifier, the more complex to use, and the more ambiguous the information provided, all increase the cost of performing the mission. Better to have a single isotope identifier that can be easily used by a dozen security personnel than a dozen isotope identifiers that can only be partially used and, therefore, are only minimally effective in the mission.

That being said, obviously the lowest cost isotope identifier that completely meets the mission requirements is the most efficient solution.

3.0 Single Detector Options

As might be expected from the mission requirements, it is difficult to find a single detector identifier that meets all the requirements. The requirement for large collection volume, high efficiency, high-resolution across the energy spectrum is difficult for a single detector to meet at a reasonable cost. In addition, without being paired to an integrated neutron detector, single detector systems have limited capability against heavy shielding.

3.1 Sodium Iodide

Sodium Iodide-based isotope identifiers remain the detector of choice of the majority of systems available on the market. NaI is the most mature and least expensive of the scintillation detectors, allowing large crystals to be grown at reasonable prices. These large crystals provide NaI with excellent collection efficiency over a wide energy range of photons. For the cost point, NaI performance for the Detection mission is unmatched. For the identification mission, the NaI capability for precision spectroscopy is limited. At 6% to 7% energy resolution at best, NaI is insufficient to perform discrimination between large numbers of isotopes. With a highly trained and experienced operator working through ambiguities, the NaI detector can provide a great deal of information about any isotope. However for a less trained individual, an NaI identifier is challenging to use for unambiguous identifications.

3.2 Cadmium Zinc Telluride

Cadmium Zinc Telluride (CZT) can be seen as having inverse performance to the NaI detector. CZT is very expensive to grow in crystals large enough to provide good collection efficiency, so is not very affordable at performing the Detection mission. Smaller, more affordable crystals, are very inefficient at collecting medium and high energy photons. However, CZT has excellent energy resolution for the Identification mission. Mass production resolutions of 1.5 to 2% are sufficient to allow discrimination between large numbers of isotopes, requiring very little training and experience from the operator. The ratio of crystal size to cost is the primary limitation of CZT.

3.3 Lanthanum Bromide

Lanthanum Bromide (LaBr) detectors combine some of the best properties of both NaI and CZT. A large LaBr crystal has high collection efficiency and performs the Detection mission very well. LaBr has good resolution performance, on the order of 3%, and provides good discrimination between large numbers of isotopes. Similar to CZT, the crystal size to cost ratio is much higher than NaI.

4.0 Sensor Fusion

The solution to increasing the dissemination of isotope identifiers into security forces, and increasing the level of radiation security, is through sensor fusion. That is, combining the strengths of multiple detector technologies to eliminate the weaknesses of each one individually. This approach allows the strengths of mature detection technology to be combined with new detector technology at an efficient cost while still meeting all performance requirements. If, alternately, new detector technology was required to meet all areas of the performance envelop, the system cost would be necessarily high. Sensor fusion allows an affordable isotope identifier to be fielded that is both an excellent detector and an efficient high-resolution identifier, reducing the level of training and technical understanding required by the user to deal with ambiguities.

Note that sensor fusion is not achieved by simply integrating multiple sensor capabilities into a single system. There are many isotope identifiers that provide a potpourri of additional detectors that can be added or swapped. While these optional detectors add performance capability to the trained and experienced user, they actually add complexity and subtract from ease-of-use, increasing training and mission costs. The purpose of fusing multiple sensors is to make the operator's mission easier to perform with less training and less ambiguity, and at an efficient cost point.

4.0 Sensor Fusion, Cont.

At the most basic levels, sensor fusion can include just using each detector in its area of strength and not in its area of weakness. For instance, a large NaI crystal can be used as an excellent detector and can also be used for medium-to-high energy photon spectroscopy. A smaller (and thereby less expensive) array of small CZT or LaBr detectors can provide excellent low-energy resolution as well as adequate collection efficiency of low energy photons (due to the cumulative volume of the array). Combining the NaI and CZT/LaBr detectors together provide an excellent capability in both the Detection and Identification missions.

At a higher level of sensor fusion, NaI and CZT peaks can be correlated to improve the resolution of the medium-to-high energy NaI peaks, mitigating the poor collection efficiency of the small CZT detectors at those energies. Similarly a large volume neutron detector with an integrated moderator is needed for the Detection mission, but can also be used in the Identification mission to correlate specific SNM isotope identifications. These capabilities require no additional complexity for the user and in fact, since they reduce ambiguity, lessen the operator's workload.

The downside of sensor fusion is that it requires multiple sensors. Each of these sensors requires drive electronics, read electronics, and power. The detectors have to be arranged in a tight package without shielding each other, and each adds weight and volume. The packaging can never be as small as a single large LaBr or CZT crystal solution. However even single crystal solutions are limited in size and weight by the detector package, the display screen and controls, and the batteries. The benefits of sensor fusion across the mission requirements are a satisfactory trade for size for all but the most discrete isotope identifier missions.

5.0 Conclusion

To improve the level of radiation security requires that isotope identification systems be useable by personnel with little understanding of radiation physics and low levels of training. Yet the isotope identifier must perform its mission to the highest levels of performance. The cost of the identifier must be as low as possible, given these requirements, to maximize the number that can be acquired.

These requirements can best met by sensor fusion across multiple detectors. As new technologies are available in the future, it is likely that sensor fusion will still provide the optimal means to control costs without any sacrifice of performance or capability over a single crystal solution.