Challenges for Interdiction of Nuclear Threats at Borders

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Abstract -- Countries around the world are deploying radiation detection instrumentation to interdict the illegal shipment of radioactive material crossing international borders at land, rail, air, and sea ports-of-entry. These efforts include deployments in the U.S. by the Department of Homeland Security and in a number of European and Asian countries by governments and international agencies, such as the International Atomic Energy Agency. Items of concern to be interdicted include radiation dispersal devices, special nuclear material, and nuclear warheads. Radiation portal monitors are used as the main screening tool for vehicles and cargo at borders, supplemented by handheld detectors, personal radiation detectors, and x-ray imaging systems. This paper focuses on the challenges of background radiation, radionuclide identification, and interference sources to interdiction.

Index Terms – border security, radiation detection, nuclear threats

I. INTRODUCTION

The events of September 11, 2001 and other terrorist events, and concern over the possible transport of illicit radioactive materials across international borders by terrorist organizations has led to the development and deployment of radiation detection instrumentation used to interdict such potential activities. The radiologically detectable materials of concern include operational nuclear weapons, improvised nuclear devices (INDs), special nuclear material (SNM), including plutonium (^{239}Pu) and enriched uranium (^{235}U and ^{233}U) for construction of such weapons, and material or assemblies for radiological dispersal devices (RDDs) [1]. Federally funded programs have been established in the U.S. within the Departments of Homeland Security, Energy, State, and Defense to deploy equipment around the country, and the world, for the interdiction of such illicit materials. The International Atomic Energy Agency (IAEA) has also deployed radiation interdiction equipment [2].

The detection and identification of radioactive material in commerce are difficult tasks. At a busy border crossing, as opposed to a laboratory environment, only very short times are available in which to perform these measurements without adversely affecting commerce. Daily, the more than 600 ports-of-entry in the U.S. see more than 300 000 vehicles, approximately 2500 aircraft, and nearly 600 ships [1].

Passive radiation detection techniques use large gamma ray and neutron detectors to look for enhanced radiation emissions that are above normal background. Large fixed instruments and handheld or belt-worn radiation detectors are used for routine scanning of vehicles, cargo, and material crossing the borders. Active radiation detection techniques include x-ray or gamma ray imaging for hidden materials, and neutron or gamma ray induced signatures for explosives and SNM. Generally, deployments utilize a layered defense where various technologies and trained individuals are used to interdict contraband, and intelligence information may also lead to targeting of certain vessels or cargo.

All of the targeted radioactive materials produce a gamma radiation signature. In addition, plutonium is an emitter of neutron radiation. Generally, the size of a source that would be useful for an RDD of any consequence (kilocuries of activity) would be fairly large and thus relatively easier to detect than SNM. The masses of SNM of interest are on the order of the amounts designated by the IAEA as “significant quantities” of interest: 8 kg of plutonium and 25 kg of highly enriched uranium (HEU) [3]. The detection of HEU from its low energy gamma-ray emissions is the most difficult task.

For the majority of the screening performed on cargo and vehicles at border crossings, large fixed radiation portal monitor (RPM) systems utilizing plastic scintillator gamma-ray detectors and ^3He -based neutron detectors are commonly used. The RPMs were developed initially at national laboratories and were commercialized for contamination screening and for screening of scrap metal for inadvertent sources [4]. Since 2002, Pacific Northwest National Laboratory (PNNL) has been deploying such RPM systems on behalf of U.S. Department of Homeland Security (DHS) Customs and Border Protection (CBP) at U.S. ports-of-entry. With over 1100 of these RPM systems deployed to date, over 97% of all containerized cargo is currently being scanned with RPMs at U.S. borders and ports-of-entry (POE).

A plastic scintillator based on polyvinyl toluene (PVT) is the most common gamma ray detector used in RPMs. Since these detectors indicate the presence of gamma radiation without providing much information about the full gamma ray energy, additional detectors are required to provide identification of a source that triggers an alarm in a RPM. This identification step in the interdiction process is generally provided by handheld radio-isotope identifier devices (RIIDs) that typically use NaI(Tl) scintillation detectors. The American National Standards Institute (ANSI) has developed standards for the testing of such radiation detection equipment in order to provide minimum requirements for radiation detection instruments for border security applications [5].

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II. BACKGROUND RADIATION

Natural background radiation observed in radiation detection instrumentation arises from terrestrial and extraterrestrial sources [6]. The bulk of the observed background gamma radiation comes from ^{40}K (half-life 1.3×10^9 y), ^{232}Th (half-life 14×10^9 y) and ^{238}U (half-life 4.5×10^9 y), and their daughters, in the ground and building materials surrounding the detector, with an additional contribution from cosmic rays and solar sources. The flux of the gamma ray background varies significantly with geographic location and also shows a dependence on the weather and solar activity.

The bulk of the neutron background observed arises from the cascade of particles produced by cosmic rays. This neutron background is fairly constant with a strong dependence on altitude and some variation with solar activity [6], [7]. There is an increase in the neutron signal observed from some dense cargos due to a phenomenon called the “ship effect” [8].

Balancing the two requirements at the border of non-interference with commerce and accurate measurement for radiation is a difficult task. It is made more difficult by the presence of background radiation and non-threatening radioactive materials, such as medical radionuclides, that may be present in patients that have been recently treated, and naturally occurring radioactive materials (NORM) being legally transported [9], [10]. The presence of NORM is an every-day part of commerce, and is neither a threat to national security nor the health and safety of border inspection personnel or others involved in commerce [11]-[15].

There are a number of man-made legal sources of radiation that are found in normal commerce that are generally higher in activity and smaller in volume than NORM sources. These sources include medical radionuclides and specialized commercial products. Based on the total number of radiopharmaceutical procedures per year in the U.S., the medical alarms are estimated to occur once for approximately every 2600 American passengers passing through U.S. borders [10]. The most prevalent medical isotope is $^{99\text{m}}\text{Tc}$. Examples of specialized commercial radiation sources are those used for radiation sterilization, weld examination, liquid level gauges, and, in some older gauges and instruments, radium-containing paints.

Operational limitations exist for the detection sensitivity of RPMs, the most prominent being the existence of NORM in cargo, medical-related alarms, multilane cross-talk, the shadow shielding effect, and interference from radiography sources [9], [10], [16]. Naturally occurring radioactive material is a significant limitation when screening cargo vehicles or containerized cargo, since it is the cause of most nuisance alarms from cargo. Some border crossings have more than 10 000 vehicles per day. If just 1% of these contain enough NORM to produce a nuisance alarm, roughly 4 vehicles per hour would be sent to secondary screening (rescanned in a different place than the primary lane), driving the need for significant personnel resources. Naturally occurring radioactive material is much less prevalent in personally owned vehicles (POV) and in small items such as

luggage and packages. For POV screening, medical related alarms are the major contributor to the nuisance alarms.

Simple detection of the presence of radiation in cargo crossing the border does not provide the information necessary to identify the isotopic source of that radiation, and therefore cannot be used alone to determine whether the radioactive source is innocent or illicit. This identification activity is handled in a secondary screening process using a NaI(Tl) or high-purity germanium (HPGe) gamma-ray detector. Spectroscopic portal monitor systems that potentially have the capability for discrimination of innocent and illicit radioactive materials with spectrometric methods are being developed and tested. These systems, designed to supplement or replace current RPMs, utilize NaI(Tl) detectors with sufficient energy resolution to provide isotopic identification [17], [18]. Until such time as spectroscopic portal monitor systems are available for deployment at border crossings, progress is being made to reduce the number of nuisance alarms in existing radiation portal monitors through improved analysis algorithms [19]-[21].

III. INTERFERENCE SOURCES

Interference with the correct operation of radiation detection equipment can be produced by nearby sources being used to perform x-rays imaging for security or industrial purposes. Radiography sources are often found in industrial environments that surround a POE, especially at seaports. These sources may be far away from the radiation detection instruments, such as RPMs, but can still produce interference. The x-ray imaging sources are often closer to the RPMs, being used within the POE for interdiction purposes, but typically have lower impact than the radiography sources, since the imaging systems are usually under the control of CBP. Both of these sources can interfere with RPMs either through direct line-of-sight radiation or indirectly through scattered radiation, especially “skyshine.”

Skyshine, the radiation scattered in the air above a high-activity source, can produce interference with radiation detection systems at very large distances, even up to many hundred meters. Skyshine has been studied for many years for accelerator applications [22], and more recently within the context of nuclear power and radioactive waste storage (see for example, [23]-[29]), for considerations of health physics effects. These studies show that modeling of skyshine must take into account third order scattering (i.e., photons scattered up to three times in the air contribute significantly to the spectrum) and must incorporate huge spatial volumes, since photons will scatter multiple times and return to the surface at large distances from the source. Additionally, scattered radiation loses its original identifying spectral characteristics.

Even low numbers of residual photons, well below the number to produce health concerns, can cause interference in high-sensitivity radiation detection instruments, such as those used for homeland security applications. The impact of skyshine on RPMs is the same whether they are based on PVT, HPGe or NaI(Tl) detectors, and the possible mitigation approaches to the skyshine interference problem are similar.

There are three main approaches to dealing with skyshine interference:

1. Avoidance: install RPMs in, or relocate RPMs to, locations where skyshine is not a problem.
2. Administrative: raise thresholds to avoid nuisance alarms from skyshine or limit the use of RPMs (manually or automatically) during skyshine events.
3. Shielding: shield either the radiography source or the RPMs.

The first two approaches are utilized to the extent possible, but may not be totally effective or possible for all sites. Therefore the third approach is necessary. The amount of shielding to eliminate the impact of skyshine is substantial, since the scattered photons come from all directions. The only effective shields are large and expensive to build.

IV. CONCLUSIONS

Most border crossings in the U.S., as well as many in other countries, have instrumentation for the detection and identification of radioactive materials that may be transported in cargo. Most detected radioactive sources are innocent materials since so many items shipped in cargo contain some amount of radioactivity.

Since all radiation alarms must be further investigated by border security officers, any reduction in the number of nuisance alarms improves the efficiency and effectiveness of radiation screening. It is a difficult task to detect, identify, and thereby interdict, the illicit movement of radioactive sources. Because a possible act of terrorism would involve a radioactive source that might include a number of dangerous radionuclides up to and possibly including an actual nuclear weapon, interdiction is judged to be necessary. This screening at border crossings is but one component of a layered defense of methodologies being used to interdict terrorist threats.

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