IPNDV Working Group 3: Technical Challenges and Solutions
High Explosives (5)—Technology Data Sheet

October 27, 2016

High Explosives (HE) Technology Name: X-ray Backscattering Imaging

Physical Principle/Methodology of Technology:

Photoelectric absorption and Compton scattering are the main interaction mechanisms for X-rays below 1 MeV when impinging into a target. Cross-section for photoelectric absorption depends significantly on the proton number of the target nuclides (Z) and the energy of X-rays (E_γ), i.e., the cross-section is proportional to Z^4/E_γ^3. The cross-section for Compton scattering is not sensitive to the target proton number Z. Therefore, its probability is nearly constant per unit mass of any material [g/cm^2]. These behaviors mean that if the inspected object is made from light elements, low Z material, Compton scattering has a better chance to compete with the photoelectric absorption.

With low X-ray energies, the probability for Compton backscattering is nearly equal to forward scattering. At higher energies the probability for backscattering decreases significantly. Figure 1 can be used to calculate the energy of the backscattered photon E_γ' as a function of the initial photon energy E_γ.

Figure 1: Formula to Calculate the Energy of Backscattered Photon E_γ'

$$E_\gamma' = E_\gamma/(1+E_\gamma/0.255\ \text{MeV})$$

As shown above, the backscattered photon E_γ' has lower energy than E_γ and therefore, its probability for absorption is also higher if we assume that both photons travel through the same material thickness. The significance of this effect is smaller if the photons are only traveling in low Z material.

Placing all these factors together it can be concluded that the X-ray backscattering technique suits well for the inspection and analysis of objects made of light elements. Imaging capability can be realized, for example, using a scanning photon beam.

Normal X-ray technique suits better for the imaging of objects that contain higher Z materials.

Potential Monitoring Use Cases (pre-dismantlement, dismantlement, post-dismantlement, storage stage):

X-ray backscattering imaging produces two dimensional images of the inspected objects. This technique could be used to determine the sizes and shapes of high explosives after the dismantlement process when they are placed inside a non-metallic container.

Physical Description of Technology (e.g., approximate size, weight):

Handheld (weight 4 kg) X-ray backscattering instruments that produce real-time images are commercially available. They are battery powered. Their operating time with one set of batteries is 4 hours.

Time Constraints (e.g., measurement times including distance from object, time to install the equipment):

Because the X-ray backscattering is an active technique and the match between the current operational Use Cases and the proposed application is good, the measurement times should be quite short. Of course images might need to be taken from different angles of the container. This would naturally also

increase the time required for the analysis of data. Analysis should be automatized and performed behind an information barrier. The exact distance from the object is not critical but typically quite tight measurement geometries are preferred when, for example, searching for narcotics inside a vehicle's tires.

Technology Complexity (e.g., hardware, software, and ease of use by personnel):

Imaging equipment for operational field use based on this technology are commercially available. Front line officers, also having other duties, routinely operate these instruments. Images are automatically generated from the data.

Infrastructure Requirements (e.g., electrical, liquid nitrogen, etc.):

One can operate these devices using battery power. The batteries require recharging.

Technology Limitations (e.g., operational temperature range, differences in materials):

The technology can be operated indoors without problems because current commercial instruments are developed to work within 0 ^{o}C to 45 ^{o}C temperature range. The battery lifetime presents some limits to the usability of the instruments.

Information Collected by the Technology (used to help determine if an information barrier is required for use):

The technology gives the size and shape of high explosives.

Safety, Security, Deployment Concerns:

Because these devices produce X-rays that exit the instrument, one needs to take care of the radiation protection of the users.

Technology Development Stage (Technology Readiness Level, TRL):

TRL 7. The X-ray backscattering imaging is in operational field use in other applications but they have never been applied for the nuclear disarmament verification.

Additional System Functionality (e.g., outside the monitoring use case):

It is trivial, but this technology can also tell if there are other objects than high explosives inside the transport/storage container.

Where/How the Technology Is Currently Used (e.g., international safeguards, border protection):

The X-ray backscattering equipment are used to screen suspicious objects such as unattended bags and packages. They are also used to inspect vehicles on the border crossing points or to secure spaces used, for example, in high-threat VIP events. These instruments are able to detect hidden substances made of light elements such as drugs and explosives.

Examples of Equipment:

MINI Z handheld X-ray scanner, available at http://as-e.com/products-solutions/cargo-vehicle-inspection/handheld-inspection-2/product/mini-z/.