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“Tomographic” X-Ray Diffraction Explosives Detection Technologies

Source: Safran

Homeland Security Research Corp.

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1.1 "Tomographic" X-Ray Diffraction Explosives Detection Technologies and Application

(**Source**: Private communication with Xylon)

1.1.1 Introduction

As we (HSRC) believe that since 2002 the next generation of EDS-based screening will and must be augmented on automated Explosives Detection technology based on an X-ray Diffraction technology (we elected to provide the reader with an in-depth description of the technology and its application.

The Coherent X-Ray Scatter, an automated Explosives Detection technology based on an X-Ray Diffraction technology was first developed in 1990-1999 by the Industrial X-Ray Division of Philips GmbH and its successors YXLON GmbH.

The system utilizes an energy-dispersive diffraction technique to identify a wide range of substances based on the differences in the molecular structure of materials. The specific implementation of this diffraction technique uses an energy resolving detector array to detect scatter at a small fixed angle. A C-Arm scanner maintains the alignment of the X-ray source and detector and scans baggage transversely, while it is transported through the system on a conveyor. The entire bag is scanned to generate three dimensional materials-specific using coherent scatter spectra that are automatically evaluated to determine if materials of interest, such as explosives, are present. The resulting scatter spectra provide information regarding the molecular structure of the scattering materials.

The technique provides a means to identify and discriminate between different materials at a level that is unsurpassed because it is a molecular-based technique. This inherent discrimination capability enables the detection of a wide spectrum of explosives while simultaneously rejecting virtually all other materials. Recent testing of the technology by German and Israeli aviation security agencies demonstrated levels of detection previously believed to be unachievable while simultaneously achieving minuscule false alarm rates. The technology is in use in several countries, including Israel and Germany.

Figure 1 - Morpho XRD 3500 System

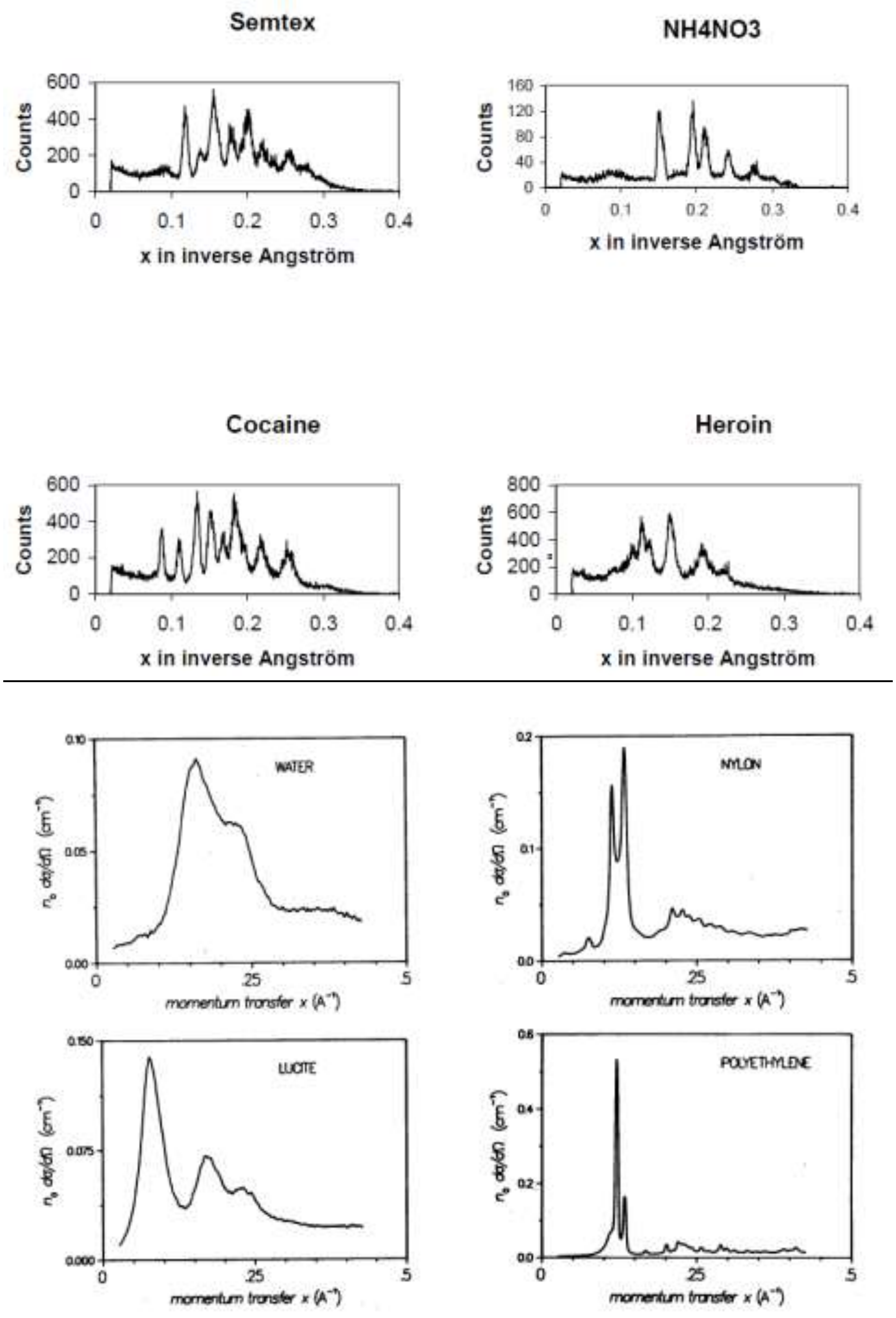
1.1.2 Principle of Operation

A high-power X-ray tube is located above the inspection tunnel as shown in the Figure below. The X-ray tube beam is collimated by a primary collimator that shapes the beam into a cone and penetrates the bag from above in a localized area. As with most interactions between X-rays and an item under inspection, the X-ray energy penetrates the item, and is absorbed and scattered by it. A secondary collimator and high-energy resolution detector assembly detects the scattered radiation in the same direction as the primary X-ray beam at a very small fixed angle from the primary beam. A high energy resolution detector is required because the scatter partials are detected at a fixed angle in the energy dispersive configuration.

The detector is divided into annular segments such that scatter is detected from a number of distinct horizontal regions simultaneously over the full height of the inspection tunnel. This detector configuration, therefore, provides scatter information that is resolved in the vertical direction.

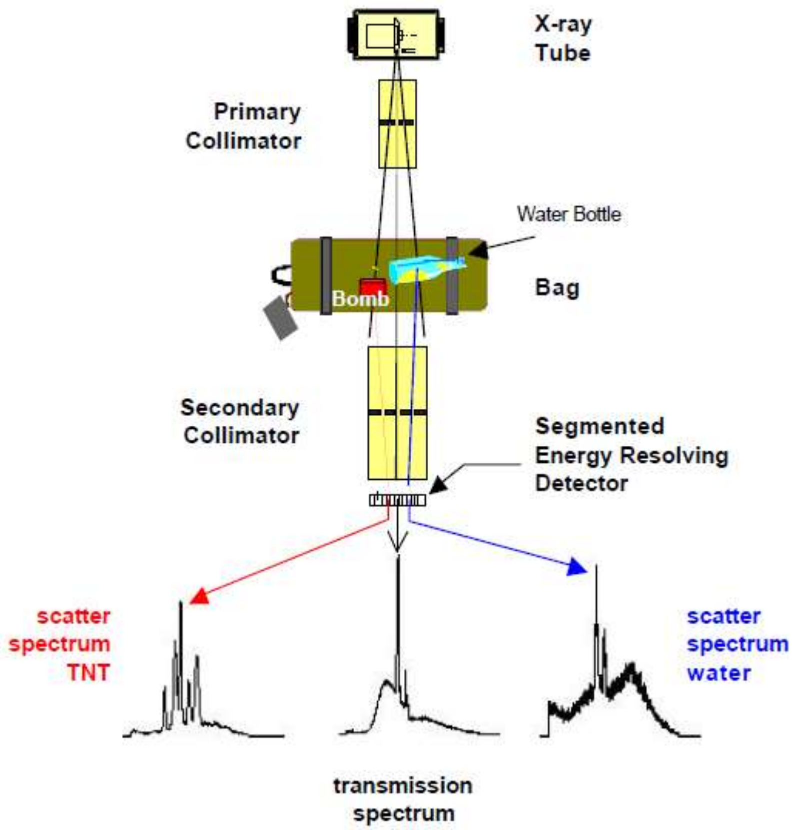
The X-ray source and detector set are scanned across the inspection tunnel to collect data from a "strip" across the entire bag to provide scatter data that is spatially resolved in the horizontal direction. This process is replicated until data is collected from the entire bag. The scanning rate, speed of the conveyor, geometry of the X-ray beam and the dimensions of the detector segment have been developed to create voxels which have the same dimension in each direction. Data collected from the voxels of a given bag creates a three-dimensional representation of the bag with respect to scatter data. The scatter data from each voxel are analyzed over a range of X-ray energies to create individual scatter spectra for each voxel.

Figure 2 - X-Ray Diffraction Spectra of Explosives, Drugs & Benign Materials



The individual scatter spectra are then compared with an extensive library of spectra for targeted materials. If there is a match, the system alarms and reports the location of the voxel or voxels and identifies the material detected.

Figure 3 - X-Ray Diffraction Technology: Cone Beam Geometry,Detected Scatter and Transmission Spectra



1.1.3 Automated Level 2-3 Localized Scanning Screening

The X-Ray Diffraction technology is used as a "localized inspection" mode to inspect small suspicious "volume of interest" a given bag rather than the entire bag. Localized screening limits the inspection process to areas of the bag that have been identified as suspicious or non-definable by a previous screening step. Limiting the screening to suspicious areas results in a significant increase in the number of bags that can be screened per hour with high levels of confidence.

When used in an automated Level 2 Localized Scanning Screening mode the system receives baggage rejected by a preceding EDS screening stage.

The X-Ray Diffraction technology was specifically designed to inspect and resolve baggage that has been rejected as suspicious by previous screening steps performed by an automated system or/and operator. Equipment selected to perform the final screening step in a multi-step screening process should be capable of rendering decisions with a very high level of confidence.

Since each step in a multi-step screening process is designed to reduce the number of bags rejected to the subsequent step, the number of bags that reach the final resolution step is a small fraction of the total number of bags screened. A lower inspection rate is, therefore, acceptable for screening equipment used at the end of the process.

The time required for an X-Ray Diffraction technology inspection of a given bag increases proportionally with the size of the bag and inversely with the mass of explosives to be detected.

Many multi-step hold baggage screening installations require the initial screening stage to inspect up to 1,800 bags per hour. Systems currently utilized for initial and secondary screening applications are based on dual energy X-ray techniques and EDS. These systems are operated at levels of detection approved by pertinent authorities, but they also reject a large percentage of bags as suspicious. The high reject rates produced by these systems are undesirable because of the additional procedures required to inspect and resolve rejected bags.

The lack of a proven automated solution to efficiently screen reject bags has resulted in relegating the burden of resolving suspicious bags to human operators viewing X-ray and EDS images. The operator is required to perform this difficult final screening resolution step for suspicious baggage under significant time pressure. This crucial step of dealing with suspicious baggage is strongly influenced by several human factors, a constant sense of urgency and the additional pressure that rejected bags will require more intensive and therefore more time-consuming and costly screening procedures.

Attempts to utilize only X-ray, EDS and ETD systems to reduce or eliminate the use of operators to inspect bags rejected by initial screening systems have not been successful to date. The fundamental problem has been that the reject rates of the systems tested in the secondary position have been too high. Although dual-energy X-Ray and EDS is based on different physical characteristics (effective atomic number and mass density respectively) their performance is more similar than originally expected.

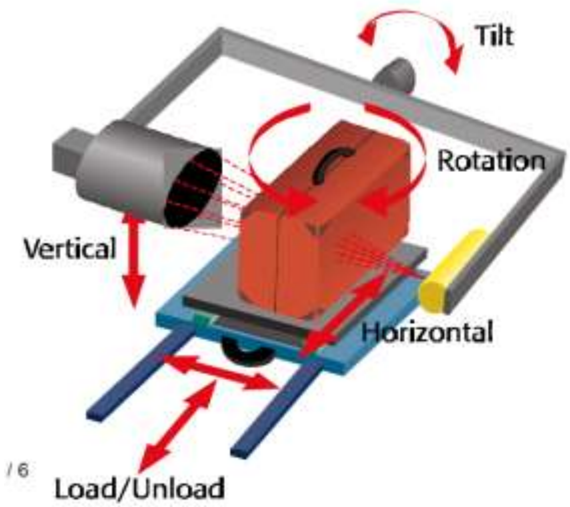
The similarity in performance results in an increase in the reject rate of the secondary inspection systems when used to screen bags that have been rejected by an initial screening system. The initial screening system tends to clear the same bags that the secondary system would be able to clear. However, by removing the "easy bags" the initial screening system creates a more difficult spectrum of bags for the secondary system to inspect. The combined performance of these systems is essentially limited by the undesirable similarities in their performance characteristics. This would not be the case if the systems exhibited vastly dissimilar performance characteristics but the lack of a disparate system has precluded cost-effective solution.

1.1.4 Localized Inspection Using X-Ray Diffraction Technology

A general protocol has been developed for the communication between other explosives detection systems and the Model XES 3500 system to enable the automatic inspection of baggage rejected by preceding systems. A substantial increase in throughput is achieved by confining the inspection performed by the XES 3500 to threat regions that have been identified by the preceding system. This mode of operation is commonly referred to as localized inspection.

The addition of localized inspection capability is an extension of the capabilities of the current system as the only difference is how much of the bag is scanned or inspected. Accordingly, the addition of the localized inspection capability does not diminish the performance of the system when used as a final resolution system to inspect entire bags.

Figure 4 - X-Ray Diffraction Technology Localized Scanning Assembly



A robust and reliable focused inspection capability has to ensure that threat regions defined by preceding systems are correctly identified and scanned by the X-Ray Diffraction technology system. The concept used for accomplishing baggage registration is to compare X-ray projection images from the upstream and X-Ray Diffraction technology systems. An X-ray image is generated immediately prior to the entrance of the X-Ray Diffraction technology system to maximize the accuracy of the baggage registration system. The coordinate transform is computed by applying well established and proven image comparison techniques to the two X-ray images. Some additional considerations to ensure that the implementation of the technique is robust include the following:

The match between the bag and related data package must be confirmed to ensure that the bag matches the data that has been communicated on a global basis. This check is designed to prevent inspecting a bag based on the data package for a different bag. This situation can occur when the baggage handling system (BHS) loses positive control of baggage, as a result of an emergency shut down, a die-back condition or following a power interruption.

This condition can also be caused by the intentional or unintentional injection or removal of a bag from the BHS, a miss-read condition or a no-read condition in addition to numerous other conditions. Global bag matching also helps to detect drastic or unusual changes of a bag's orientation on the conveyor.

Failure to pass the global match test results in the bag being returned to an upstream system for re-screening or full inspection by the X-Ray Diffraction technology system.

Given a global match between the bag and data, a coordinate transform is computed for any change in position of the bag that may have occurred during transport from the preceding system to the X-Ray Diffraction system. The coordinate transform is computed for any shift in the bag relative to the conveyor as well as around a vertical axis.

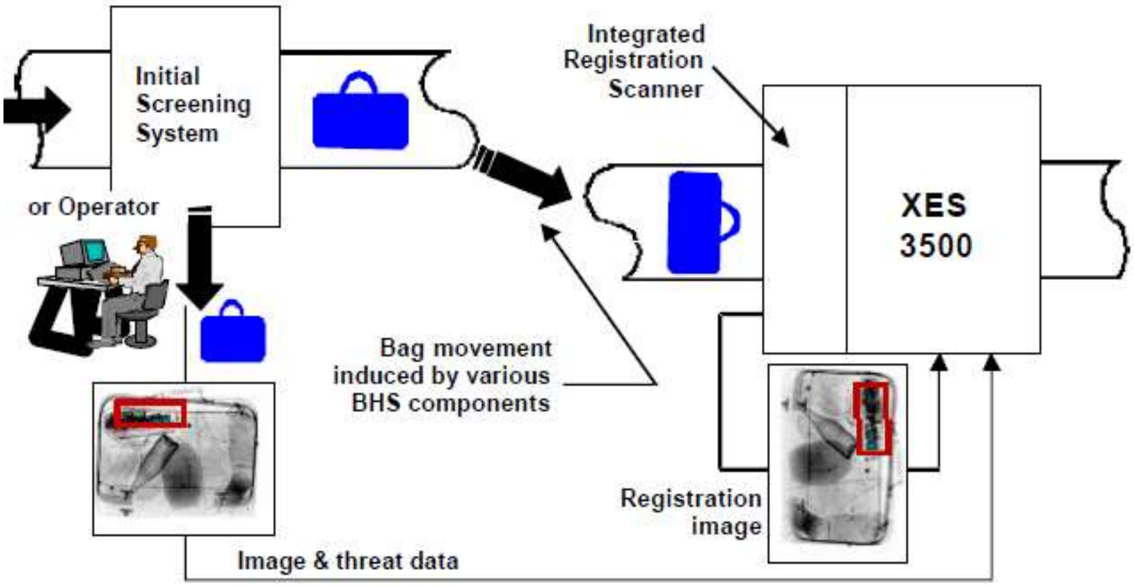
Figure 5 - EDS, BHS and (XRD 3500) X-Ray Diffraction systems

(**Source**: Morpho)

The threat regions identified and reported by the preceding system are enlarged slightly prior to ensuring that localized inspection of the area of interest is accomplished.

The reduced alarm rates offered by the model X-Ray Diffraction system significantly reduce the number of bags to be rejected to the final inspection stage for resolution by an operator. The image provides the operator with crucial additional information to evaluate the bag to determine if the bag can be cleared or should be subjected to additional security screening procedures. The threat resolution image may also be used to support the reconciliation of the passengers and suspicious baggage.

Figure 6 - Explosive Detection System with X-Ray Diffraction Technology Localized Scanning Link



Pros:

- ❑ This is "the only game in town" for true 3D X-ray providing better detection than 2D X-ray in many cases.

Cons:

- ❑ Disappointing error rate (false negative/positive). The figure depends upon the system and the screener's level of expertise. It is HSRC's opinion that in confronting sophisticated explosives, these systems will perform poorly.
- ❑ There are complaints that real-life false alarm rates hover at around 20-30%.
- ❑ Performance is operator-dependant.
- ❑ Every new CT technology undergoes several years of reliability problems; tomographic EDS is no exception. A breakdown of tomographic EDS at peak times can disrupt traffic unless very significant investments in redundancy have been made.
- ❑ High maintenance costs due to 24/7 operation and X-ray tube replacement requirements.
- ❑ The system does not detect WMD. However, the metallic components in nuclear devices may be detected.

1.1.5 Hybrid Tomographic Explosive Detection System & 2D X-ray Screening

The combination of these technologies is designed to save scanning time – a major obstacle in deployment when the system was designed in the early 1990s. In this configuration, the object (luggage/parcel) undergoes an initial two dimensional X-ray imaging. If the first pass identifies a suspicious area, this area undergoes tomographic scanning.

1.1.6 Explosive Detection System Certification

In the U.S., the TSA supports EDS development through multiple processes, but is most significantly involved in the final stages of EDS development when EDS equipment needs to be assessed and approved. Assessment and approval are under the auspices of the Transportation Security Laboratory (TSL) under two separate consistency assessments. The first is System Qualification Testing (SQT) which includes vendor-accomplished developmental testing and is not detection-related. The second is a detection-related conformity assessment which depends primarily on TSL testing and consists of a Certification Readiness Test (CRT) and a formal Certification Test.

- **Non-Detection Related Assessments** Prior to SQT, the TSL reviews, witnesses and approves vendor Developmental Test and Evaluation (DT&E) at the vendor's plant. Following the DT&E, the TSL would conduct SQT involving selected demonstrations conducted at the TSL site for non-detection requirements such as operability, reliability, usability, safety, communications, interfaces with conveyor controls, data loggers, training kits, information security, maintainability, emissions compatibility and susceptibility and environmental factors.

  On average, the SQT phase takes approximately thirty calendar days to complete.

  After successful completion of SQT, the TSL would conduct separate tests to verify detection requirements (i.e., CRT and the Certification Test), as discussed in the following section.

- **Detection-Related Assessments:** A detection requirements conformance test which is a condition for entry into formal Certification Testing. During the CRT, TSL and vendor personnel interact as an integral part of the EDS development process. The CRT is a relatively large and complex test design aimed at detecting specific algorithm deficiencies using a large number of unique test states.

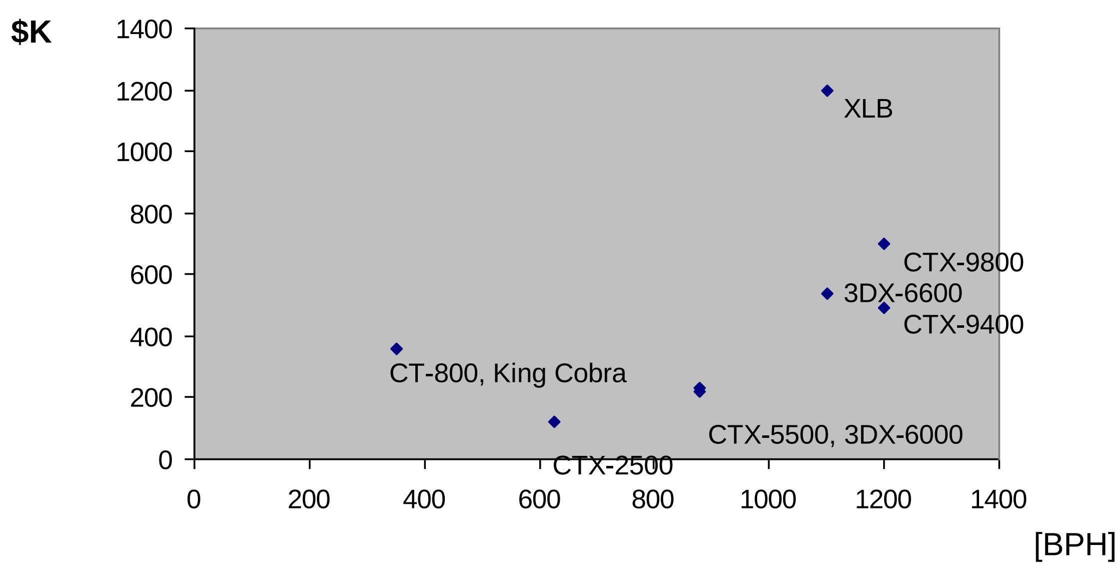
  On average, the CRT takes approximately ninety calendar days to complete.

1.1.7 Explosive Detection System Throughput vs. Price

In 1988, the FAA in the U.S. established a Security Equipment Integrated Product Team (SEIPT) for the procurement, engineering and installation of checked luggage screening equipment. This mandate was evolved for the SEIPT to address Walk-Through Metal Detectors, passenger Threat Image Projection (TIP) X-ray screening equipment and ETD as well as checked luggage screening systems – EDS. Over the past several years, new machines with better performance characteristics (such as XLB, CTX-9400 and CTX-9800) entered the market. Nonetheless, scanning is still operationally and financially inefficient. It is particularly ineffective in detecting "smart" explosives configurations and WMD.

The following chart describes modern EDS equipment in co-ordinates of price and realizable throughput (in bags per hour). Note the poor correlation between the various systems prices and their throughput.

Figure 7 - EDS Throughput [BPH] vs. System Price [$K]



More information can be found at:

Tomographic Explosives Detection Systems – EDS & BHS: Industry, Technologies & Global Market – 2014-2020