IPNDV Working Group 3: Technical Challenges and Solutions
High Explosives (2)—Technology Data Sheet

July 1, 2017

High Explosives (HE) Technology Name: Fast Neutron Interrogation System for HE Identification

Physical Principle/Methodology of Technology:

In the process of neutron irradiation, the neutrons are either captured or scattered. In scattering, the neutrons collides with the nucleus, which either remains in its ground state but with additional kinetic energy from the neutron (elastic scattering) or is activated in a short lived excited state (inelastic scattering) and usually returns to the ground state by emitting a gamma-ray. Whether the scattering is elastic or inelastic is determined by the energy of the neutrons, the nucleus and its neutron cross section. When a neutron is captured by the nucleus, the new nucleus is usually left in an excited state. It returns to a stable state by emitting one or more gamma-rays or other particles. The energy of emitted gamma-rays are characteristic of the target nucleus.

Neutrons from the source penetrate the material and cause gamma-ray emission through inelastic scattering or capture. Systems that use these methods use neutron sources for interrogation and gamma detectors to determine the composition of the scanned material or a presence of certain elements.

Fast neutron interrogation: (or fast neutron analysis, FNA) offers several advantages over thermal neutron interrogation (or thermal neutron analysis, TNA). As the cross-section for inelastic scattering of fast neutrons (at 14 MeV) is larger than the cross section of thermal neutron capture of most nuclei, fast neutron analysis can identify not only nitrogen but also C and O. High energy (typically 14 MeV) fast neutrons, usually from a portable neutron generator, scatter (inelastic) and cause emission of characteristic scattering gamma-rays.

The *associated particle imaging* (API) technique, also known as the tagged neutron method, is based on the time and direction correlation between fast neutrons (14.1 MeV–5.2 cm/ns) and alpha particles (3,5 MeV–1.3 cm/ns) produced by D-T reaction. Detection of the alpha particle with a position-sensitive detector provides ("tag") the direction of flight and time of emission of the associated neutron. As the neutron scatters on the interrogated material nuclei, emitted gamma-rays are detected by the gamma detector and the energy spectrum of the gamma radiation determines the elemental composition of the interrogated material. The time of flight measurements (t_{alpha} and t_{gamma}) help determine the depth on the interrogation cone where the reaction occurred, therefore creating a possibility of imaging. On the other hand, the almost simultaneous detection of alpha and the gamma-ray significantly helps improving the signal to background ratio (200 times better), by disregarding the unassociated gamma-ray detections.

Pulsed fast neutron analysis (PFNA) or pulsed fast-thermal neutron analysis (PFNTA) are other neutron-based systems that are also considered for the detection of bulk organic materials as explosives.

The fast neutron interrogation is associated with a gamma detector (gamma camera) for detection and identification and optionally with a conventional X-ray detector for imaging.

This technology is an active and non-destructive measurement system.

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

Fast neutron interrogation and associated particle detection offer the ability to obtain the chemical composition (C,H,N,O) and the mass estimation on many kinds of organic materials, whose explosive, inside a container. Neutrons are emitted toward the shielding and the unknown object. As a result, the atomic interactions produce element-specific gamma-ray emission, which allows to determine the stoichiometry of analyzed matter. Explosive composition is derived from comparing the detected gamma-ray energy spectra with a database (library) in the electronics module of the portable device.

Potential monitoring use of fast neutron technology are post-dismantlement (phase 9 of simple scenario) and storage stage (phase 10 of simple scenario).

The use for pre-dismantlement and dismantlement cases (phases 6 to 8 of simple scenario) has to be investigated previously due to safety issues regarding to nuclear materials (14 MeV—fast neutron emission) and due to shielding issue (between HE and experimental apparatus).

For detection technologies, what does the method determine/measure:

The method measures the gamma-ray energy spectra of the investigated bulk material that allows user to determine some specific chemical proportions (C, H, O, N) of the explosive by comparing with a spectrum database.

The identification of the type of HE present (e.g., TATB, HMX, RDX) may be possible (to be demonstrated) if the database (library) has been previously implemented with the right spectra of the explosive molecules, in accordance with the measurement configuration.

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

The system is a portable device: 32 kg–currently 60 × 60 × 40 cm.

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

The portable case contains the neutron emission system, the alpha and gamma detectors, an electronic module, a high voltage power supply, and a video camera. The case is connected to a distant laptop through an Ethernet cable. Typically, the case is placed next to the container/object and activated from a safe distance (10–30 m).

Laptop PC centralizes data processing and provides a user-friendly interface. In case of explosive detection, the software delivers the quality (type of explosive) and quantity (weight) assessments, with the indication of a confidence level.

After turning power on, the detection is automatic. The typical detection time is from 2–10 minutes with a 20 second display refresh.

Will this method work in the presence of shielding? If so, what is the maximum amount of shielding that will still allow the method to work?

The neutron energy spectrum should be modified in dense organic shielding, leading to changes in the relative intensities of the induced gamma-rays. For that reason, the method will have to be tested and calibrated in representative conditions to improve accuracy.

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

This is an all-in-one portable equipment simple to use (typical users are inspectors and bomb squad in charge of security).

Database (library) for explosives identification is implanted in the electronics module.

The portable case is connected to a distant laptop that centralizes data processing and provides an assessment in a short time (<5’) through a user-friendly interface.

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

No unusual requirements are required.

Electricity: 110V/230 V.

Technology Limitations (e.g., detection limits for HE, operational temperature range, differences in technology detector materials):

Operating temperature: 10 to 40°C; relative humidity: 10 to 90% (non-condensing); dust and water: IP54.

Neutron flux: 10^6–10^8 n/s at 14 MeV

Radiation dose: lower than 2.5 microSv/h at 24 m.

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

Information collected about HE: presence/absence, detailed molecule, mass evaluation and, optionally, location inside the container and shape (possible 3D image), depending on the technology used (TNA, FNA, API, etc.).

An information barrier (IB) will be required to protect sensitive information (shape, precise mass, and composition of HE device).

Safety, Security, Deployment Concerns:

Safety concerns due to neutron source have to be taken into account. But the radiation exclusion zone is included in (usual) pyrotechnic exclusion zone for workers. The restricted area size (when operating) depends on allowed dose rate on operators (10 m means about 10 microSv/h).

Neutron-explosive interaction could entail safety difficulties in regard of national regulations.

Technology Development Stage (Technology Readiness Level, TRL):

The technology has been developed for homeland security (e.g., airports, trains, stations, airline baggage, subways) and other military or civilian infrastructures to face the threat of terrorist attacks or illicit traffics (e.g., drugs).

Commercial systems exist and work for usual explosives; it must probably be tested for some specific high explosive materials. TRL 6–7 (specific demonstration required for TATB with shielding).

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

The technology is also used for detection and identification of illicit drugs.

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

Neutrons are one of the few methods available for element analysis of hidden objects. They are suitable for exploring large volumes due to their ability to penetrate thick layers of materials and interact with inspected objects. Detection techniques rely on the fact that the explosives contain H, C, N, and O in various ratios. This means that the problem of explosive identification is reduced to the problem of identification of light elements.

The technology is well suited for use on many different substances, e.g., explosives or drugs. It has been used for homeland security (e.g., cargo or baggage inspection) for explosives detection and fielded by military organizations to detect explosive (e.g., buried explosives, etc.).

Examples of Equipment:

Company name: SODERN (France)
Equipment name: ULIS (Unattended Luggage Inspection System)
Equipment type: Associated Particle Imaging (API)

Company name: APSTEC (Russia)
Equipment name: SENNA
Equipment type: Associated Particle Imaging (API)