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Advances in neutron based bulk explosive detection

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Abstract

Neutron based explosive inspection systems can detect a wide variety of national security threats. The inspection is founded on the detection of characteristic gamma rays emitted as the result of neutron interactions with materials. Generally these are gamma rays resulting from thermal neutron capture and inelastic scattering reactions in most materials and fast and thermal neutron fission in fissile (e.g. ^{235}U and ^{239}Pu) and fertile (e.g. ^{238}U) materials.

Cars or trucks laden with explosives, drugs, chemical agents and hazardous materials can be detected. Cargo material classification via its main elements and nuclear materials detection can also be accomplished with such neutron based platforms, when appropriate neutron sources, gamma ray spectroscopy, neutron detectors and suitable decision algorithms are employed.

Neutron based techniques can be used in a variety of scenarios and operational modes. They can be used as stand alones for complete scan of objects such as vehicles, or for spot-checks to clear (or validate) alarms indicated by another inspection system such as X-ray radiography.

The technologies developed over the last two decades are now being implemented with good results. Further advances have been made over the last few years that increase the sensitivity, applicability and robustness of these systems. The advances range from the synchronous inspection of two sides of vehicles, increasing throughput and sensitivity and reducing imparted dose to the inspected object and its occupants (if any), to taking advantage of the neutron kinetic behavior of cargo to remove systematic errors, reducing background effects and improving fast neutron signals.

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1. Introduction

Nonintrusive inspection of concealed explosives using neutron and other nuclear based techniques started seriously over two decades ago following the Air India disaster in the first half of the 1980s. The objectives of this type of inspection are to look for explosives in objects as small as a briefcase and as large as a truck and marine shipping container. The size of explosives, measurement time and the concept of operation are quite varied for the different cases. The basis however, is always the same: look for the elemental signatures and deduce from them the presence or absence of explosives.

The chemical composition of explosives (military, commercial and home made) and many other threats are sufficiently different from benign materials, so that the determination of the concentration of some or most of the elements in the inspection zone affords the ability to distinguish between benign and threat materials. As an example, Table 1 provides the elemental composition of some threat and benign materials.

Neutron and other nuclear based techniques detect the presence of explosives through a variety of nuclear reactions which can be categorized by the type of probing

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Table 1
Elemental composition of some typical explosives, chemical agents and benign materials

	C	H	N	O	P	F	Cl	S	N/H	N/C
Threat										
C4	21.9	3.6	34.4	40.1					10	2
TNT	37	2.2	18.5	42.3					8	1
PETN	19	2.4	17.7	60.8					7	1
AN	0	5	35	60					7	
Chemical agents										
Sarin	34.3	7.1		22.9	22.1	13.6				
VX	49.5	9.7	5.2	12	11.6			12	1	
CA (H-Cyanide)	44.5	3.7	51.8						14	1
HD (Mustrad gas)	30.2	5					44.6			
Phosgene	12.1			16.2			71.7			
Benign materials										
Water		11.1		88.9						
Paper	44	6		50						
Plastic	86	14								
Salt							60			

source particle, its energy and time profile and type of signature particles and their energy. There are "neutron in"/"gamma ray out" techniques employing gamma ray production through thermal neutron capture and neutron inelastic scattering interactions. There are also"neutron in"/"neutron out" techniques employing neutron broad resonance elastic scattering. Also "photon in"/"photon out" techniques were studied, where photon resonance scattering has been employed. "Photon in/fission signatures (neutrons and/or gamma)" techniques are being used for detection of fissile materials (see this proceeding). Photo activation techniques are available but not commonly used for explosive detection because of the required high energy of the source and low cross sections. The principles and status of these techniques have been periodically reviewed (e.g. [1–3]).

Recent advances in detection of bulk explosives (and other threats), not covered in the previous reviews cited above, are briefly reviewed below. We will concentrate on the detection of explosives, such as terrorist car and truck bombs, that are aimed at inflicting the maximum deaths and destruction.

2. Recent advances

Recent advances in explosive detection, resulting in higher detection sensitivity and operational flexibility, were accomplished in several areas:

(1) Increased reliability of neutron generators.
(2) Better neutron head design to improve neutron efficiency and reducing collateral radiation exposure.
(3) Faster electronics and digital data processing.
(4) Two parameter (time-energy) data acquisition allows better signal to noise and makes a wider range of signatures accessible.
(5) Improved algorithm and larger data base.
(6) Different system configurations for different applications.

3. Head design

An example for a head design to achieve item 2 above is shown in Fig. 1. A similar design retained a very good sensitivity to bulk explosive while reducing the dose rate for

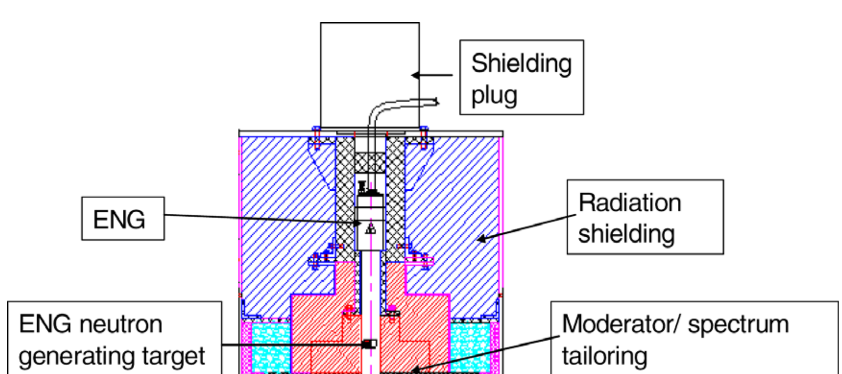

Fig. 1. Electronic Neutron Generator (ENG) head designed for high sensitivity and low off-axis radiation dose rate.

wide angles (<75) off-axis at about 1 m and 2 m from the source axis (where, for example, a truck driver may be sitting) to below 50 and 5 μrem, respectively, for a 10 s inspection with a 14 MeV neutron source intensity of 10^8 n/s. These radiation doses are a factor 100–1000, respectively, lower than one receives in a coast to coast flight over the USA.

4. Two parameter data

The ability to use a full two parameter – time and energy – analysis of the gamma ray spectra resulting from the injection of fast neutron pulse into an inspected cargo offers important improvements to the system performance. It allows for measuring the capture gamma region, essential for the detection of nitrogen, which is a key element in most explosives, over the optimal time domain: shorter when the cargo is highly hydrogenous and dense and longer when it is non-hydrogenous. This assures the attainment of the highest signal at the lowest background. Collecting spectra following the complete decay of the thermal neutrons allows detection of any neutron induced activation, for example, that of oxygen through the (n,p) reactions of neutrons with energies above 10 MeV. The activation spectrum on its own provides an alternative signature for oxygen. It also enables the subtraction of this and other activations, as backgrounds from the capture (n,γ) spectrum. An example of the information provided by the two parameter analysis is shown in Fig. 2. The spectra measured over three time intervals for a cargo made of copy paper which also contained ammonium nitrate sample simulating explosives, are shown in this figure. Very different pieces of information can be gleaned from these spectra. From the one taken during the neutron pulse, the carbon content (mostly from the paper cargo) may be inferred. From the thermal capture time domain (the domain in paper over which the thermal neutron "die away"), the presence of nitrogen, a key ingredient of explosives and hydrogen (mostly from the paper cargo itself) can be determined. The "activation" time gate, lasting from a few milliseconds after the pulse until the next pulse, shows various sources of a constant (on the ms time scale) background for the capture regions, which could now be subtracted away, enhancing the signal to background ratio of the capture spectrum. The oxygen (from the paper cargo) can now be measured very precisely as a signature on its own merit. If the cargo were of a different composition, e.g. low or non-hydrogenous metallic, the spectra could easily identify its overall composition and its neutron time behavior. With this information the proper time gates can be chosen to obtain the best signal to background ratio. Knowledge of the type of cargo from the very same measurement offers the possibility of using a decision algorithm which is optimized for the observed category of cargo.

5. Wide range of configurations

Figs. 3 and 4 provide examples of different configurations of explosive detection systems, which were built to fulfill very different operational requirements. Fig. 3 shows a track mounted truck inspection system, which scans from both sides a stationary vehicle. This configuration is suitable for inspecting vehicles at entrance to facilities or at any other traffic chock points in land and sea ports. Fig. 4 shows a man-portable or light transportable system that can be battery operated, be carried in a passenger car and brought onto boats and set up in a short time to conduct an inspection for the presence of explosives or drugs behind walls. Most of the systems described above can be

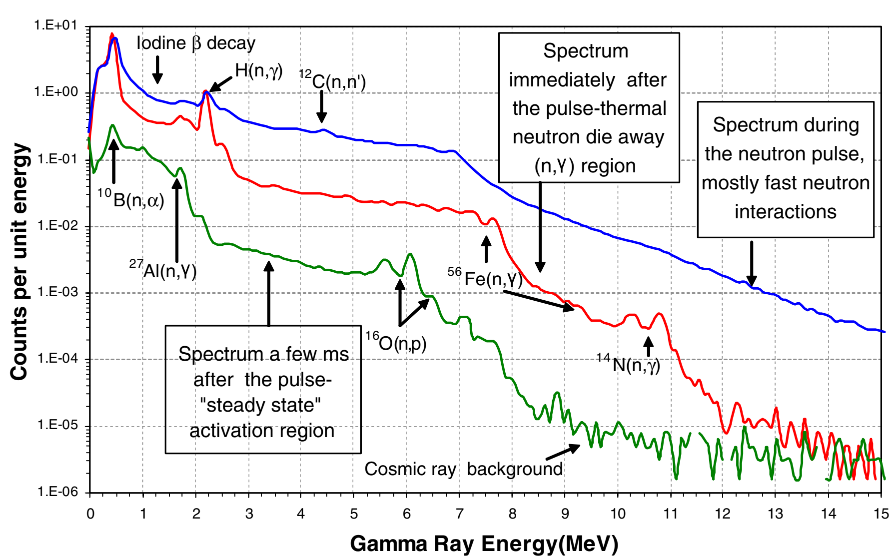

Fig. 2. Gamma ray spectra accumulated over different time gates as measured by NaI detector during and after repetitive pulses of 14 MeV neutrons are incident on a cargo of copy paper (density 0.65 g/cc) containing an ammonium nitrate explosive simulant. The Fe and Al signals are from structural materials in the source and detector head. The boron signal is from the shielding material in and around the source head.

Fig. 3. Truck inspection for explosives via track mounted, two sided pulsed neutron inspection.

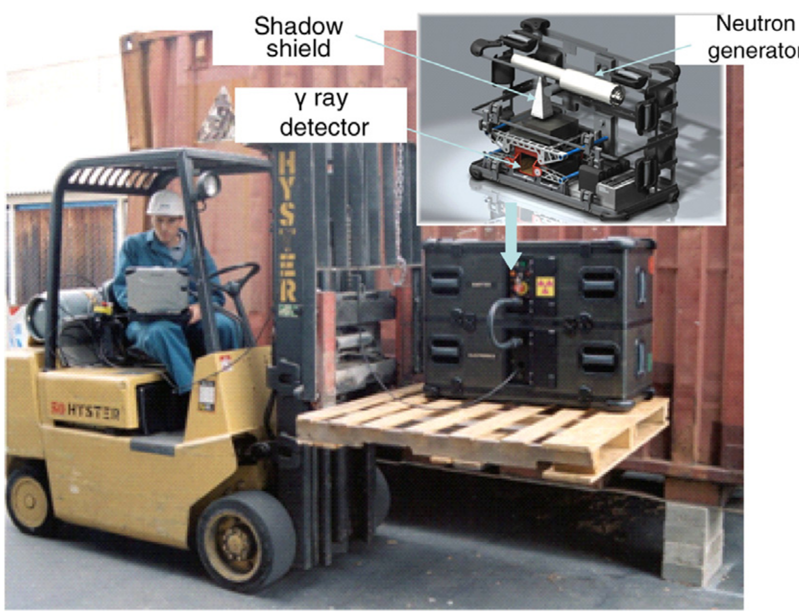

Fig. 4. Man-portable/light transportable pulse neutron inspection system. The inspection system is brought to the inspection location and positioned using a light fork-lift.

expanded to include fission signatures to also allow inspection for fissile materials.

6. Conclusions

We have very briefly reviewed the fundamentals of neutron based explosive inspection. Different configurations of the system have been developed to meet the varied applications of bulk explosive detection for the Department of Homeland Security. Advances in small accelerators, electronics, data acquisition and decision algorithms are leading to higher sensitivity, higher throughput and lower collateral radiation fields.

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