Explosives detection: it's all connected

Abstract This article links the main challenges in explosives detection to terrorist scenarios, and provides a view on future opportunities for explosives detection systems and technological developments as a part of a comprehensive counter terrorism approach. A few trends and highlights are given with a focus on European multidisciplinary research collaborations.

Keywords **Explosives, terrorism, detection, research, European collaboration.**

Résumé **La détection d'explosifs : tout est lié**
Cet article relie les principaux défis de la détection d'explosifs aux scénarios terroristes et donne un aperçu des opportunités futures pour les systèmes de détection d'explosifs et les développements technologiques dans le cadre d'une approche globale de lutte contre le terrorisme. Quelques tendances et points forts sont présentés, mettant l'accent sur les collaborations de recherche multidisciplinaires européennes.

Mots-clés **Explosifs, terrorisme, détection, recherche, collaboration européenne.**

Explosives are used since long in terrorist attacks and have inflicted human suffering and generated dramatic material damage. Major events occurred at the end of the 80s and the 90s in western countries, for instance the attack on the Pan Am plane which crashed over Lockerbie, and the attacks at the federal building in Oklahoma city and the Paris metro [1]. These events led to an increase in security measures, especially at airports. But it were the attacks in Madrid (2001) and London (2005) [1] which can be considered, especially in Europe, as the starting point of extensive research and development programs of new explosives detection technologies.
The physical and chemical properties of explosives, or its precursors, together with the terrorist scenario/modus operandi ("red side") and the operational environment in which the explosive threat should be detected ("blue side") are critical aspects to be understood and explored in order to select the proper detection solution to enable intervention of terrorism activities and counter the explosive threat (*figure 1*).

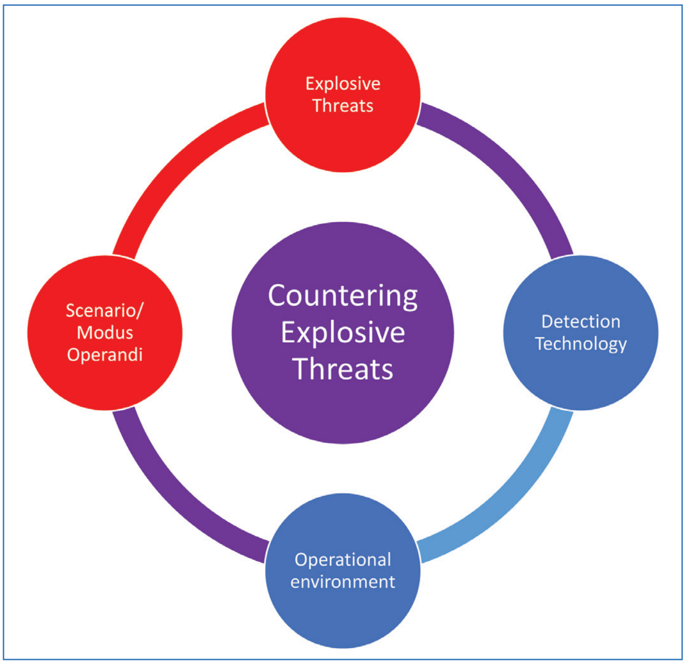

Figure 1 - Interlinked aspects of countering the explosive threats.

Explosive threats

Explosives can be classified in different categories. For instance, explosives can be liquid or solid and there are many more ways to categorize. From a technological perspective, a relevant distinction is to discriminate between two different threat amount categories, which are trace and bulk amounts of explosives. Besides detecting the explosive substance (or its precursors) directly, one can also look for other improvised explosive device (IED) components, such as detonators, timing or trigger devices, shrapnel or wires.
There is no scientific consensus on the definition of "trace" or "bulk" amounts, but in general trace amounts are defined such as what cannot be seen by the naked eye. The amount of explosive for traces is in the range of picograms up to about 0.1 milligrams. Bulk amounts can be categorised ranging from parts of a milligram up to many kilograms or even tons of explosives. Sometimes a small amount of explosive material, still visible to the naked eye, is defined as residue. There is no direct relation between the presence of a trace amount of explosives and the presence of a bulk amount of explosives. Nevertheless, the detection of a trace amount of explosives, especially vapour, may indicate the presence of a bulk amount of explosives. *Figure 2* illustrates the difference between trace and bulk amounts of explosives.

Scenario and modus operandi

The timeline of a terroristic activity contains several phases, together describing a high-level scenario, that can have a wide span over years or smaller time windows such as weeks and days [2].
- Preparation phase (including IED assembly): the time needed for the preparation phase will depend on the type and amount of explosive, e.g. a home made explosive (HME), the way to obtain this explosive or its precursors and the time to manufacture the IED. In any case, there is time available for countermeasures such as explosives detection.
- Transport phase: once the IED is packaged, it will be transported to the target and the time available for intervention will be shorter.

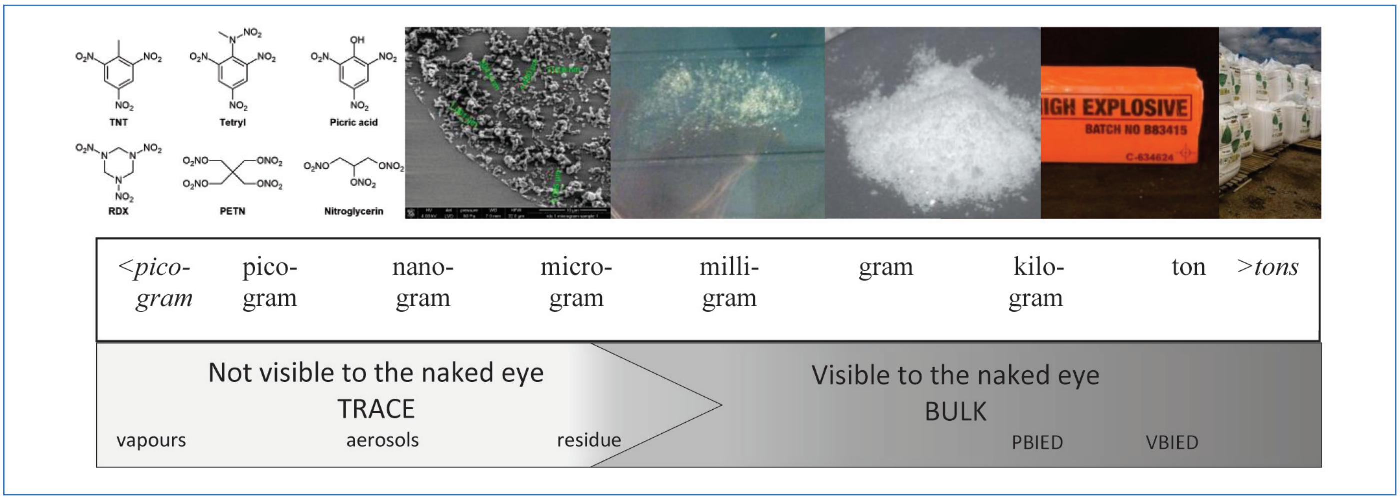

Figure 2 - Illustration of traces and bulk amounts of explosives (PBIED: personal borne IED; VBIED: vehicle borne IED). Based on information in [14].

- Execution phase: initiation of the IED is imminent on arrival at the target location, though the IED may be time delayed by the terrorist with the purpose to achieve a certain effect.

Going further into detail, the methods for producing homemade explosives (HMEs) and IEDs [3] and modus operandi of the terrorists are as wide as their imagination. The production can take place in different environments ranging from urban to rural. A few important main modus operandi categories can be distinguished as related to the transport and execution phase: the personal borne IED (PBIED), the bag/package "leave behind" IED and the vehicle borne IED (VBIED). Each of these has sub-categories. For instance a leave behind object could be a bomb hidden or disguised in bags or rubbish sacks, or could be carried to the attack location by a person (or possibly with a vehicle) and left there by the person who subsequently leaves the location. VBIEDs are bombs in vehicles, to be detonated either in suicide attacks or parked and subsequently detonated. Scenarios include vehicles that are parked at the street or in car parks, and vehicles that are moving slowly or are briefly stopped. In each of these phases, opportunities are present to detect the explosive and thus preventing the attack. In general, the time available for intervention and counteracting an attack decreases as the respective timeline phases approaches the execution phase.

Explosives detection technology

Two performance characteristics are important in explosives detection: sensitivity and selectivity. Sensitivity relates to the minimum amount of an explosive material required for detection. The detection device must be able to detect sufficiently small amounts of explosives related to a certain scenario. Selectivity is the ability of a system to correctly provide information on the type of explosive. Sensitivity is highly related to the probability of detection, while selectivity is highly related to the probability of false positives. For both trace, bulk and anomaly detection various technologies exist, each with its own pros and cons, both in detection performance characteristics, as in operational use.

Operational context

The applications of explosives detection technologies are diverse. Each operational environment involves specific operational conditions and detection devices must be suitable for the situation. Especially the combination of the situational control and the expected modus operandi of the terrorist are of importance to the situation at hand. This combination leads to a certain technology need.

From an operational perspective, situational control is the degree to which law enforcement and security personnel can control the aspects relating to the successful detection of an explosive or IED, like weather, available time and cooperation of people. Situational ranges from high, like in an aviation security checkpoint, to low, like in an open crowded urban place. Some typical operational settings are entrances to critical infrastructure (CI), aviation security checkpoints, land and sea border checkpoints, mass transportation, crowded places and HME/IED production locations. The general tendency in this list is from high to low situational control.

It's all connected

On a high level some of the main technology needs can be identified beforehand. As stated in the previous section on detection technology, a high sensitivity is associated with a high probability of detection. High sensitivity is needed in situations where minimising false negative results is important. A high selectivity is associated with a low number of false positives. High selectivity is of importance for situations where false positives have a large adverse effect on the flow of screened persons or objects, since each positive result needs to be resolved, which takes time and burdens the person in the event of person screening. While the time to obtain a result from detection equipment should be as short as possible in any situation, it is more pressing in the execution phase of the terrorist plot, when the attack is imminent. Stand-off(1) (people) screening is an application where the distance is 10-100 metres or more, in order to screen people or objects and carry out interdiction at a sufficient distance to provide for some protection for the target and/or the screener against the explosion effects. In some specific situations it is desirable to screen persons or objects while moving. With walk-by people screening, preferably at a modest stand-off distance, e.g. 1-5 metres, formation of queues and consequent disruption to commerce and everyday life is reduced or even avoided. Other situations require the availability of mobile, transportable equipment, for instance in the event of a leave behind IED or in the detection and location of an HME production location. To summarize research and development should be driven by threat assessments in the context of the operational environment of the detection technology. Of course operational and cost drivers should be considered.

Multidisciplinary European research collaborations

Collaborative research efforts are crucial and typically involve a broad range of expertise that in a multidisciplinary fashion creates an exhaustive approach for addressing complex issues. A selection of previous and on-going European research projects[(2)] is presented in which CEA, FOI (Swedish Defence Research Agency) and TNO (Netherlands Organisation for Applied Scientific Research) took part, together or individually. The projects are sorted by the terrorist scenario phases as described earlier: preparation, transportation, execution.

HMEs take time to produce and can create dispersions of used chemicals to the surroundings. For example in the London bombings in 2005, the bomb factory was located in an urban apartment where hydrogen peroxide was used as an ingredient. The handling and preparation of this volatile compound disperses vapours to the surroundings through e.g. ventilation exhausts.

In the LOTUS project [4], this scenario was explored by testing (mobile) detection devices mounted on vehicles. The devices were calibrated for different precursors and also contained a GPS so that the type and amount of the substance detected could be tied to a timestamp and the location presented on a map. The idea was to develop and test a capability that could detect e.g. hydrogen peroxide from a certain distance and with sufficient selectivity and sensitivity. The results from the trials were promising and the research on localisation of bomb factories was continued in the EMPHASIS project [5], which focussed on a different concept of using static sensors with the capability to scan the air over large distances for monitoring precursors using spectroscopic techniques.

The common denominator for all IEDs is the explosive. There will arise needs to transport explosives to e.g. a safe haven, a storage space between the point of acquisition and the manufacturing location, or the transport of the assembled IED to the place of execution. When explosives are acquired outside the border of Europe or outside a country border where the attack is aimed for, these need to be transported via border controls with an apparent risk of being detected. The use of HMEs in attacks are common, probably because consumer chemicals can be purchased in the geographical proximity of the execution.

The project XP-DITE [6] aimed to develop, demonstrate and validate a comprehensive, passenger-centred approach to the design and evaluation of integrated security checkpoints at airports. The project EFFISEC aimed at providing a higher security level of identity and luggage control of pedestrians and passengers inside vehicles, at land and maritime check points, by the integration of a set of existing and complementary technologies (biometrics, e-documents, signal recognition and image analysis, trace and bulk detection of substances, etc.). The project TRESSPASS [7] progressed the concept of risk-based screening at border checkpoints.

The ability to detect explosives from a distance is an apparent and desired function in explosive detection. This is called "standoff detection" and might be defined as that "individuals and vital assets should be outside the zone of severe damage". The use of standoff detection can be for interrogating a left-behind object and understand if it has explosive traces on the surface that indirectly indicate that it can contain an explosive charge or at least have been in contact with such materials. The detection may be based on laser spectroscopic techniques and requires a free line of sight to the target to be interrogated.

In the project HYPERION [8], two prototypes based on Raman and infrared spectroscopy were tested in a controlled area for detection of trace amounts of explosives between 10 to 20 metres from the object with promising results. The NATO STANDEX project [9] also addressed explosive detection from a distance. In this case detection combined microwave imaging to Raman spectroscopy.

What's the future?

The way explosives detection aspects are connected and interlinked, leaves only one way forward for enhancing the countering of the explosive threat, and that is: **collaboration**. Threats are not limited to the explosive substance. It should be broadly considered as a combination of material, IED configuration and operational scenarios. Before developing detection technologies, researchers must collaborate with the counter measures community. Law enforcement, intelligence services, operators and end-users are privileged partners to provide elements regarding the threat and its evolution. Deploying one or more detection technologies is always a trade-off between the expected threats, the desired security level, health and safety issues, inconvenience for the screened person, staff effort and operational burden, and last but not least cost.

From the detection point of view, no single technology is an answer to the multiplicity of threats and configurations. The way to enhance the efficiency of the deployed technologies or imagine new ones is the orthogonal combination of technologies at the image of checkpoints in airports (metal detection, millimetre wave and X-ray imaging, trace detection). Limiting the impact on free flow of people or goods and compliance with privacy legislation are other important requirements for a good acceptation of a new technology. These difficult challenges involve crucial need of collaborative research between industry and research technological organisations. Besides projects described above and on-going ones [10-11], an example of successful collaboration which can be considered as the origin of several research collaborative projects is the network on detection of explosives (NDE) [12]. It associated experts from eight governmental research organisations in five countries in order to support the European Commission on questions related to explosives detection.

Finally, detection activities to counter explosive threats has more aspects than only explosives detection, like for example the monitoring of suspicious money transactions or dubious travel patterns for the planning and financing phases which also need a close collaboration between law enforcement agencies, policy makers, universities, research organisations, forensic laboratories, standardisation organisations, operational users and industry. The project EXERTER [13], a network of explosives specialists, in which twenty five stakeholders are working together to counter explosive threats, is an excellent example of European cooperation, connecting almost all aforementioned categories. It's all connected.

(1) Stand-off definition: see National Research Council, *Existing and Potential Standoff Explosives Detection Techniques*, The National Academies Press, **2004**.

(2) All mentioned projects are in the FP7, Horizon 2020 or Horizon Europe framework, unless stated otherwise.

[1] J. Smith, *Brodie's Bombs and Bombings*, 4th ed., Charles C Thomas Publisher Ltd, Springfield (IL), **2016**.

[2] European Commission, "ENTRAP", H2020, 2017-2020, https://cordis.europa.eu/project/id/740560 (accessed 20 Jan. 2022).

[3] J. Ledgard, *The Preparatory Manual of Explosives: Radical, Extreme, Experimental Explosives Chemistry*, UVKCHEM, **2010**.

[4] European Commission, "LOTUS", FP7, 2009-2011, https://cordis.europa.eu/project/id/217925 (accessed 20 Jan. 2022).

[5] European Commission, "EMPHASIS", FP7, 2011-2015, https://cordis.europa.eu/project/id/261381/results (accessed 20 Jan. 2022).

[6] European Commission, "XP-DITE", FP7, 2012-2017, https://cordis.europa.eu/project/id/285311 (accessed 20 Jan. 2022).

[7] European Commission, "TRESSPASS", H2020, 2018-2021, https://cordis.europa.eu/project/id/787120 (accessed 20 Jan. 2022).

[8] European Commission, "HYPERION", FP7, 2012-2015, https://cordis.europa.eu/project/id/284585 (accessed 20 Jan. 2022).

[9] NATO, "Detecting suicide attacks – from research to reality", STANDEX, 30 Oct. 2013, www.nato.int/cps/en/natohq/news_104536.htm

[10] European Commission, "CERIS – Community for European Research and Innovation for Security", https://ec.europa.eu/home-affairs/secure-safe-resilient-societies/index_en (accessed 13 Jan. 2022).

[11] European Commission, "CORDIS", https://cordis.europa.eu/projects/fr (accessed 13 Jan. 2022).

[12] NDE, "NDE Final Report", NDE, **2013**.

[13] FOI, "EXERTER", **2018**, www.exerter-h2020.eu (accessed 20 Jan. 2022).

[14] US Homeland Security, IED Attack – Improvised Explosive Devices – Fact Sheet, The National Academies.

Oscar VAN DER JAGT[1], Senior Consultant Countering Explosive Threats, **Hans ONNERUD**[2], Deputy Research Director, and **Didier POULLAIN**[3]*, International Scientific Advisor.

[1] TNO, Ypenburgse Boslaan 2, 2496 ZA, The Hague (NL).
[2] FOI, Olof Arrhenius väg 31, 137 94 Norra Sorunda (SE).
[3] CEA, DAM, Le Ripault, F-37260 Monts.

* didier.poullain@cea.fr