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Chapter 6: Explosive Threats – The Challenges They Present and Approaches to Countering Them

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Abstract

This chapter focuses on explosives-based threats, the challenges they present and various means by which these challenges can be overcome. It begins with an introduction to explosive threats, detailing statistics regarding their use and some overarching challenges associated with properly mitigating the risks they present, before delving deeper into different areas of response by government agencies. These response areas are broadly categorized as deter, prevent, detect, delay/protect and respond/analyze.

Deterrence refers to trying to discourage people from becoming malefactors, with a focus on anti-radicalization programs and ways by which people can be dissuaded to join extremist movements. The section on prevention discusses means by which access to explosive precursor materials and information can be controlled, with a focus on polices and regulations. This includes examples of current regulations, discussion of why specific chemicals are on controlled chemicals lists, and information campaigns to raise awareness of IED threats. The following section gives a brief understanding of the important aspects to consider in detection and describes different explosives detection methods used. Approaches to delaying the use or impact of an explosive threat, as well as those that provide some sort of protection against the effects of an explosive threat, are then described. Lastly, current approaches to response to explosive threats, either before or after detonation, and the importance of analysis, are discussed before summarizing the chapter and providing a near-future outlook.

Introduction

Explosive threats, to include improvised explosive devices (IEDs), are an ongoing challenge to governments and societies around the world. The year 2016 saw 2,300 recorded incidents of explosive-based violence, resulting on over 45,000 casualties (over 21,000 killed). Almost half of the casualties were a result of IEDs. While the number of incidents varied from 2011 to 2016 (averaging 2,400 per year), the number of casualties increased by 50% over this 5-year period (Dathan 2017). This indicates that those who utilize explosives in attacks, in particular IEDs, have been successful in increasing their lethality.

The organization of this chapter will mimic the overarching approaches governments can take to counter explosive threats (Figure 1). It overlays the terrorist attack cycle (the different events and actions that take place) with a range of potential responses that governments may take explosive threats. The main text of this chapter includes five subsections: Deterrence, Prevention, Detection, Delay and Protection, and Response and Analysis. Each of the subsections discuss their respective utility and some important contributions in the field, whether they be research-based approaches, policies and regulations, or training and technical approaches. While each of the subsections are important to maintaining a diverse and effective counter-explosive threat strategy, some will be covered in more detail than others. The theme of deterrence will be covered only briefly as many of the approaches to deterrence are fundamentally not related to explosives-threats, per se, and are thus outside the scope of this chapter.

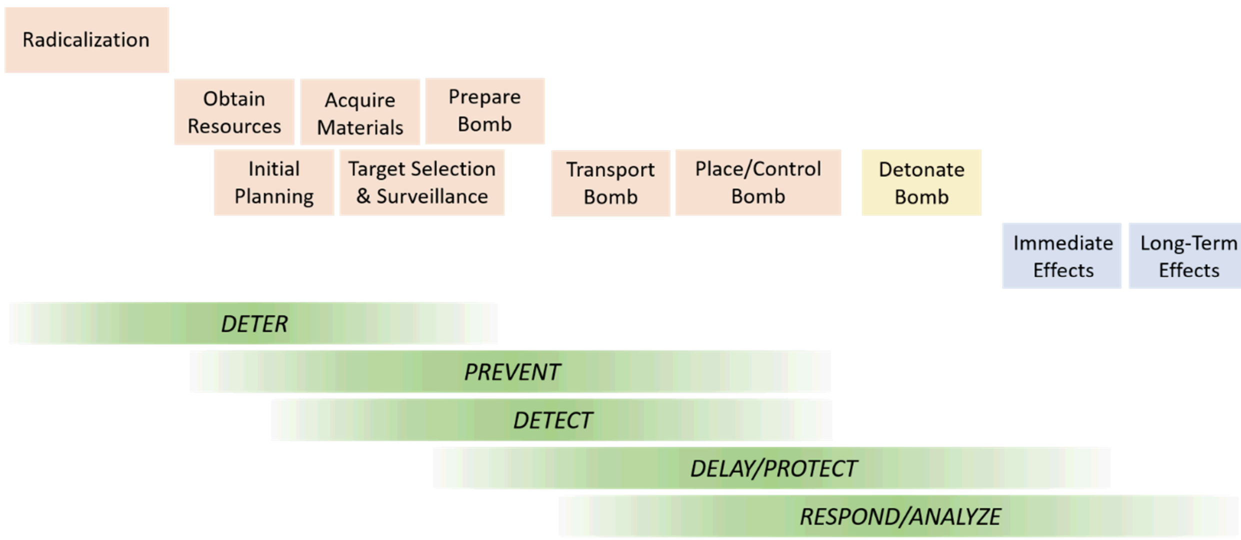

Figure 1. Illustration depicting the high-level sequence of events involved in the planning and execution of a terrorist IED attack (top) as well as categories of government responses mitigate IED threats (bottom). Adapted from the research challenges in combatting terrorist use of explosives in the United States report (Subcommittee on Domestic Improvised Explosive Devices 2008).

The 2007 United States (US) Homeland Security Presidential Directive/HSPD-19, on Combating Terrorist Use of Explosives, led to the development of a national strategy and implementation plan to counter domestic terrorist explosives use (*Homeland Security Presidential Directive 19* 2007). HSPD-19 designated the Department of Justice and the Department of Homeland Security (DHS) as the lead agencies for implementation. In 2013, the President strengthened HSPD-19 with the release of Presidential Policy Directive 17 on countering improvised explosive devices (*Presidential Policy Directive 17* 2013). In addition to these executive decisions, many other government and non-governmental initiatives have been established to counter the explosives threat, as evidenced in the list below.

Table 1. List of major entities that have a role in counter-explosive threat space, separated by government and non-government organization. This list is non-exhaustive and United States-centric.

Government Organizations	**Role**	**Website**

Department of Defense Combatting Terrorism Technical Support Office, Technical Support Working Group (CTTSO - TSWG)	Develops capabilities that support the U.S. effort to combat terrorism at home and abroad	https://www.tswg.gov/
Department of Defense Joint Improvised-Threat Defeat Organization (JIDO)	Counters improvised-threats with tactical responsiveness and, through rapid solution development and delivery, to support the Combatant Commands' efforts to prepare for and adapt to battlefield surprise in support of counter-terrorism, counter-insurgencies, and other related mission areas, including countering IEDs	https://www.jieddo.mil/ *https://www.jieddo.mil/links.htm - lists many other US Department of Defense agencies and organizations that have a role in counter-IED
Department of Homeland Security Explosives Division (EXD)	Develops new technologies and systems to protect citizens and infrastructure against the devastating effects of non-nuclear explosives, by seeking innovative approaches in detection and in countermeasures	https://www.dhs.gov/science-and-technology/explosives-division
Department of Homeland Security Office of Bombing Prevention (OBP)	Leads DHS efforts to implement the National Counter-IED policy and enhance the nation's ability to prevent, protect against, respond to, and mitigate the use of explosives against critical infrastructure; the private sector; and federal, state, local, tribal, and territorial entities	https://www.dhs.gov/obp
Department of Justice Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF)	Protects U.S. communities from violent criminals, criminal organizations, the illegal use and trafficking of firearms, the illegal use and storage of explosives, acts of arson and bombings, acts of terrorism, and the illegal diversion of alcohol and tobacco products	https://www.atf.gov/
Federal Bureau of Investigation Terrorist Explosive Device Analytical Center (TEDAC)	Serves as the single interagency organization to receive, fully analyze, and exploit all terrorist IEDs of interest to the United States	https://www.fbi.gov/services/laboratory/tedac

Interpol Chemical and Explosives (ChemEx) Program	Supports the efforts of member countries to deter, detect and disrupt the use of chemicals in terrorist incidents	https://www.interpol.int/Crime-areas/CBRNE/Chemical-and-explosives-terrorism/Introduction
North Atlantic Treaty Organization (NATO) Countering Improvised Explosive Devices Center of Excellence (CIED COE)	Assists members and partners in developing their own C-IED capabilities, with emphasis on education and training, doctrine development and improving counter-measure technologies	http://www.act.nato.int/c-ied
United Nations Office for Disarmament Affairs	Promotes disarmament efforts for conventional weapons, especially landmines and small arms	https://www.un.org/disarmament/convarms/ieds/
United Nations Mine Action Service (UNMAS)	Ensures an effective, proactive and coordinated response to the problems of landmines and explosive remnants of war	http://www.mineaction.org/unmas
Non-Government Organizations	**Role**	**Website**
Action on Armed Violence (AOAV)	Carries out research and advocacy to reduce the incidence and impact of global armed violence	https://aoav.org.uk/
Chicago Project on Security & Threats (CPOST)	Created and maintains a comprehensive and transparent suicide attack database	https://cpost.uchicago.edu/
Conflict Armament Research (CAR)	Generates unique evidence on weapon supplies into armed conflicts to inform and support effective weapon management and control	http://www.conflictarm.com/
Counter IED Report	Serves as an information source to communicate the latest developments in the fight against the IED threat	http://counteriedreport.com/

In addition, there are numerous organizations and entities that will from time to time conduct studies on explosive threats. For example, the National Academy of Sciences, Engineering and Medicine (http://www.nationalacademies.org/) periodically performs reviews and studies on approaches to countering explosives threats. These tend to be very thorough and are excellent resources to understand overarching themes related to explosive threats.

Explosive threats are any mode of attack that employs explosive materials as a means killing or maiming people, intimidating and restricting access to territory, or causing loss or disruption of physical property, critical infrastructure or vital services. While a large subset of concern within this group is that of IEDs, there are other existing threats that should be remembered and considered. Of note are landmines; there are still 61 countries that are contaminated by antipersonnel mines, with new mines used by the governments of Myanmar and Syria in the last year, in addition to numerous non-state actors (International campaign to ban landmines – cluster munition coalition 2017). Given that IEDs comprise a large portion of the current concern, the term will be used often throughout the chapter and in examples given. Many of the approaches discussed, if even in the context of IEDs, will be applicable to other types of explosive threats, such as traditional military landmines.

This chapter also touches on overarching themes in explosive threat research and development, policy and regulation. The history of explosives is not covered in detail. Neither will the progression of approaches. Instead it focuses on current and near-term counter-IED approaches and direction in research, with the majority of examples originating from the US. The US has proven to be a world leader in counter-IED and other explosives-related research. Important international approaches and regulations are also mentioned where appropriate to give the reader a brief introduction to how explosive threats are countered and references for the reader to learn more about a given topic area.

Lastly, there are many aspects of countering explosive threats that will not be discussed in this chapter for security-related reasons. As explosive-based threats are an ongoing issue, and a weapon used extensively by current terrorist and non-state actors, it is important that certain information related to governments' ability to countering these threats be controlled. For example, little will be mentioned about the role, though large and pervading, of intelligence agencies, as well as certain emerging technical solutions and training approaches. These are closely guarded by governments due to the sensitivity and importance in preventing terrorists from learning how governments seek to counter the threats they produce.

Main Text

Current state of explosive threats

Explosive devices have been around since their first use in 12th century China. The use of explosives in more improvised ways began with the use of fireships in the 17th century, where ships filled with combustibles would be set on fire and purposely crashed into targets (Coggeshall 1997). Explosive devices, both mass-produced and improvised, have evolved greatly over the years. The use of improvised explosive devices picked up in notoriety in the 1970's when the Irish Republican Army began using them frequently in attacks across the United Kingdom. Then in the early 2000's heavy use of IEDs was seen against U.S. and coalition forces in the wars in Iraq and Afghanistan. IEDs proved effective in unsettling more advanced militaries in those wars. Their use in non-warfare related events has increased in the last 15 years, particularly by non-state actors looking to cause harm and push agendas.

Various entities have tracked all, or various subsets, of explosive threats and their use globally. Organizations such as JIDO (all IED-related threats and use), AOAV (weapons-related violence) and

CPOST (suicide IEDs) all track and tabulate various statistics regarding explosive threats and attacks. While the use of explosive threats has disproportionately affected areas of active conflict (e.g., Iraq, Afghanistan, Syria, Yemen) over the last 20 years, their use as weapons of terror has increased practically everywhere. More advanced terror groups, such as Daesh, have actively researched and produced more effective and lethal explosive threats (Ismay and Gibbons-Neff 2017; Conflict Armament Research 2017). Even state actors, such as the Syrian government, have begun using more improvised explosive weapons with the use of barrel bombs and so-called “elephant rockets.” (Dettmer 2015). There are few, if any, countries that would not consider IEDs a potential or active threat that they need to be prepared for.

With the increased use of IEDs around the globe, many now have acronyms by which they are referenced. Terms such as radio controlled IED (RCIED) and victim operated IED (VOIED) are now commonplace. Table 2 shows different types of IEDs and how they are called/categorized, according to the United Nations Mine Action Service Improvised Explosive Device Lexicon (United Nations Mine Action Service 2017b). The UNMAS IED Lexicon is an excellent resource with which to learn the relevant terms, definitions and uses related to improvised explosive devices.

Table 2: List of accepted terms for different types of IED.

Name	Description
Air Borne IED	An IED delivered by or concealed in an air-based vehicle
Animal Borne IED	An IED delivered to a target by means of an animal
Command Wire IED (CWIED)	An IED that has a switch where the firing point and contact point are separate but joined together by a length of wire
Person Borne IED (PBIED)	An IED worn, carried, or housed by a person, either willingly or unwillingly
Radio Controlled IED (RCIED)	An IED with a switch that is initiated electronically by wireless means consisting of a transmitter/receiver
Radiological Dispersal Device (RDD)	An improvised assembly or process designed to disseminate radioactive material (also known as a ‘dirty bomb’)
Vehicle Borne IED (VBIED)	An IED delivered by or concealed in a ground-based vehicle
Victim Operated IED (VOIED)	An IED with a switch that is activated by the actions of an unsuspecting individual. The IED relies on the intended target to carry out some

	form of action that will cause the device to function
Water Borne IED (WBIED)	An IED delivered by or concealed in a water-based vehicle

The different types of IEDs can also employ different technologies and materials for their various components. Each of the four necessary components for any explosive device, namely, a main charge, initiator, switch and power source, can vary wildly in composition and degree of sophistication. The varying containers and camouflage used, and/or the presence of other potential components, such as shrapnel or a booster material, further increases the potential variations. For example, a fuel/oxidizer-based main charge may use any of a number of strong oxidizers (though ammonium nitrate and potassium chlorate are often used) and any of hundreds, if not more, types of fuels or variations of fuels.

Figure 2 shows the various components in an IED, to include the different types of explosives that may be used. It is important to keep in mind these different components because, depending on the situation or environment, it may be easier or harder to detect each or any of them. Additionally, it is important to remember that efforts to prevent the acquisition of materials need to be balanced, or conversely focused where it may make sense. For example, in recent years more efforts have been put towards preventing the acquisition of initiators. Commercial initiation sources are already controlled items, and, given that they are a necessary component of an IED and challenging for someone to make, therefore deserves more attention. This contrasts with switches or power sources, which, while needed, can be so varied and created from ubiquitous un-controlled items that it is nearly impossible to effectively stem their use in IED components.

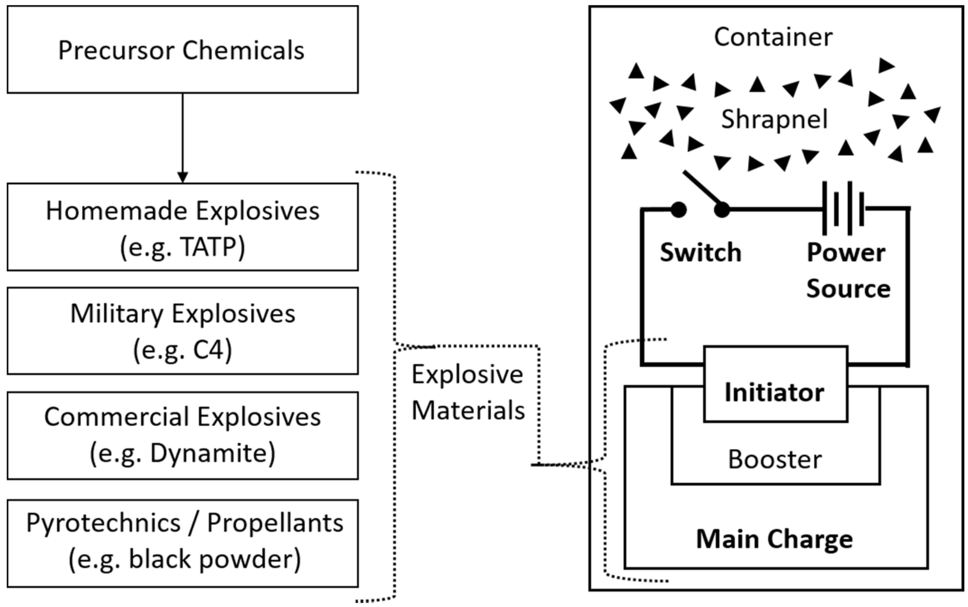

Figure 2. Schematic showing the potential sources of explosive material for an IED (left) and the required (in bold) and other often-seen components of an IED (right).

This, in addition to the variations in non-state actor use, and the targets and types of locations thereof, results in constantly evolving threats and necessitates ever-changing countermeasures to those threats. Of concern is the growing use of person borne IEDs (PBIEDs) and vehicle borne IEDs (VBIEDs). Globally, 2016 saw a 97% rise in civilian deaths from suicide VBIEDs over the previous year, and a 148% rise since 2011 (Kaaman 2017). The Chicago Project on Security & Threats (CPOST) has a substantial, searchable database on suicide IED attacks perpetrated by non-state actors around the world going back to 1974. The database is searchable by various filters, such as year, location, group, target type, etc. According to their collected data, there were 392 reported suicide IED attacks in 2016 resulting in 4611 deaths. As can be seen in table 3, suicide IED attacks and resulting casualties have been steadily increasing since 2011. And the increase is even more apparent outside of the active conflict zones of Afghanistan, Iraq and Syria (Chicago Project on Security & Threats 2017).

Table 3. Tabulated results of suicide IED attacks and casualties by year. Data from the Chicago Project on Security & Threats (Chicago Project on Security & Threats 2017).

Year	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Total Attacks by Year	259	291	477	596	636	392
Total Deaths	2396	2264	4249	5037	6117	4611
Total Wounded	6099	6154	9951	9168	11359	9085
Avg. Deaths per Attack	9.3	7.8	8.9	8.5	9.6	11.8
Avg. Wounded per Attack	23.7	21.1	20.9	15.4	17.9	23.2

Total Attacks (Without Afghanistan, Iraq, Syria)	83	119	128	155	268	153
Total Deaths	1011	861	1296	1676	3086	1731
Total Wounded	2394	2125	3287	2936	6135	4126
Avg. Deaths per Attack	12.2	7.2	10.1	10.8	11.5	11.3
Avg. Wounded per Attack	28.8	17.9	25.7	18.9	22.9	27

Deterrence

While deterrence is the first line of defense by which to counter explosive threats, it falls outside the scope of this chapter. There has been expanded interest in recent year to identify and prevent radicalization, long before an extremist may consider using an explosive threat. For example, the university of Maryland has started a new training course on understanding and preventing radicalization to violence and violent extremism (University of Maryland 2017). International organizations such as the United Nations have taken a strong interest in better understanding radicalization and the draw of extremism, both via their Office of Counter-Terrorism and their Office of the Secretary-General's Envoy on Youth (United Nations 2017a, 2017b). While this area is an important one in counterterrorism, it is not specific to explosives threats and will not be discussed in more detail.

Prevention

Another area of focus and research is in prevention; either preventing the ability to procure IED precursor materials, preventing the actual bombmaking, or even preventing the flow of information that allows one to be able to make an explosive or IED. This area in the timeline of an IED event is often referred to as "left of boom," or, before an IED has the chance to detonate. It is a desired area of focus as preventing an IED attack before the IED can even be made results in minimal loss of life. It is also, however, a very challenging area: preventing the acquisition of precursor materials and information is difficult in today's world.

There are different ways by which governments and others with an interest in counter-IED promote prevention. One is via regulatory means. Regulation is a straightforward way to target and control specific chemicals, (how they're produced, stored, transported, and disposed of). Balancing regulations to ensure that there is not undue regulation can be challenging; business still need to be competitive. Regulations can also take a long time to draft and implement and so often aren't very immediate courses of action. The United States has enacted increasingly stricter regulations targeting IED precursor materials in the hopes of stemming their illegal use. These have focused not only on rules regarding who can sell and/or buy certain materials, but also on how materials must be stored and safeguarded from theft.

One such program is the Chemical Facility Anti-Terrorism Standards (CFATS) program, administered by DHS (U.S. Department of Homeland Security [U.S. DHS] 2017b). Congress authorized this program in 2007 and provides regulations that help identify and then regulate high-risk chemical facilities to ensure they have security measures in place to reduce the risks associated with the chemicals they store. CFATS has resulted in over 4,000 facility inspections to date (Harrell 2017).

There are also various national and international regulations that govern IED precursor materials. The European Union has Regulation (EU) No 98/2013, which entered law in 2014, and seeks to enhance the protection of citizens by restricting the purchase and use of certain explosives precursor chemicals. The United Kingdom has recently updated regulations on what concentrations of explosive precursor chemicals require a member of the public to have a special license (United Kingdom Home Office 2016). The US has a list of various statutes, regulations and proposed regulations regarding the manufacture, sale and use of ammonium nitrate (U.S. Department of Homeland Security 2016). Some countries have decided to outright ban ammonium nitrate fertilizers, such as Afghanistan, when in 2010 it decided to ban the use, production, storage or sale of ammonium nitrate to try to stymie its use in IEDs in the country (Cullison and Trofimov 2010). Other countries have banned some portion of the ammonium nitrate industry, such as China, Colombia, Germany and the Philippines, with Turkey having instilled a temporary ban on all nitrates in mid-2016 in hopes of curbing IED production and use in the country (Thapliyal 2016). The ban on all nitrates except Ammonium nitrate was lifted in early 2017.

One noteworthy international program is Programme Global Shield. Programme Global Shield was started in 2010 by the World Customs Organization, in partnership with Interpol and the United Nations Office on Drugs and Crime (UNODC), to better track and monitor the purchasing, selling, and transit of fourteen different chemicals that are often found in IEDs. The program has been a success; in its initial 6-month period, over 30 metric tons of explosive precursors were seized from 19 different interdictions, resulting in at least 13 arrests (World Customs Organization 2013). It has since been made a permanent program and has recently added commercial detonators to its initial list of 14 precursor materials monitored (Table 4).

Table 4. List of chemicals and materials monitored by Programme Global Shield. Commercial detonators were recently added to the list.

Ammonium nitrate	Potassium chlorate
Acetic anhydride	Potassium nitrate
Acetone	Potassium perchlorate
Urea	Sodium chlorate
Aluminum Powder & Flakes	Sodium nitrate
Hydrogen peroxide	Calcium ammonium nitrate
Nitric Acid	Commercial detonators
Nitromethane	

In addition, the U.S. National Academies of Science, Engineering and Medicine recently published a substantial report on precursor materials for IEDs (National Academies of Sciences, Engineering, and Medicine 2017). Thorough analysis of chemicals that have been used to make explosives that are used in IEDs was completed and three groups of precursors were identified, with focus on whether the precursor chemical could be used to make a VBIED or PBIED, whether the precursor chemical had a history of use in IED attacks, and whether the chemical could be used to make a homemade explosive independent of the need for another specific chemical. Group A (highest priority) encompasses chemicals that satisfied all three of the listed criteria (with one exception, urea ammonium nitrate solution). Group B encompasses chemicals that satisfy two of the criteria, and Group C (lowest priority) those that satisfy at least one criterion (Table 5).

Table 5. Ranking of explosive precursor chemicals into three groups, with highest priority chemicals in Group A, second highest in Group B, and the remaining in Group C. Chemicals that appear in Programme Global Shield's list appear in red. Adapted from the National Academies of Sciences, Engineering, and Medicine's report titled 'Reducing the Threat of Improvised Explosive Device Attacks by Restricting Access to Explosive Precursor Chemicals' (National Academies of Sciences, Engineering, and Medicine 2017).

Group A	**Group B**	**Group C**
Aluminum (powder, paste, flake)	Calcium nitrate	Ammonium perchlorate
Ammonium nitrate	Hydrochloric acid	Antimony trisulfide
Calcium ammonium nitrate	Potassium nitrate	Hexamine
Hydrogen peroxide	Potassium permanganate	Magnalium (powder)
Nitric acid	Sodium nitrate	Magnesium (powder)
Nitromethane	Sodium nitrite	Pentaerythritol
Potassium chlorate	Sulfur	Phenol
Potassium perchlorate	Sulfuric acid	Potassium nitrite
Sodium chlorate	Urea	
Urea ammonium nitrate solution	Zinc (powder)	

The committee then went on to look at vulnerabilities in domestic supply chains for these chemicals, other regulations that international partners have enacted, and possible control strategies. The committee then provided recommendations that Congress may want to consider to reduce the nation's risk to IEDs and then listed some major topics for research priorities.

Another approach is that of simple awareness or social campaigns. One successful approach has been the "See Something, Say Something" campaign, first started in 2002 by the New York Metropolitan Transit Authority, following the September 11, 2001 terrorist attack in New York City (O'Haver 2016). The "See Something, Say Something" slogan has since been adopted nationally across the U.S. by DHS (U.S. DHS 2017c) as well as in some form or another in various other countries. While this campaign is broadly applied to any threat or emergency identified, the threat from IEDs, particularly in the form of suspicious packages has proven a strong underlying impetus. One reason for the national and international adoption has been the relative success of the program in terms of citizen response. Reports of suspicious packages in New York grew from 814 in 2002 to 37,614 in 2006 (O'Haver 2016). Although many of the reports were likely false alarms, or otherwise not of ultimate concern, the idea of using the public to be eyes and ears on behalf of law enforcement has proven beneficial in terms of stopping terrorist attacks.

There have also been more specific, IED-related awareness campaigns, both within individual countries and international associations. The U.S. DHS has the "Bomb-Making Materials Awareness Program" (U.S. DHS 2017a). The Pakistan Red Crescent Society has recently started an IED-related awareness campaign for Pakistan, with an emphasis on citizens in the Peshawar region (The Express Tribune 2017). The U.S. Department of Defense has partnered with the government of Afghanistan to provide training and materials to raise more awareness around IED threats to Afghani citizens, with a focus on children (Edgar 2015). JIDO also developed a homemade explosives (HMEs) recognition guide to assist coalition forces and Afghani forces in stemming the use of HMEs in IEDs in Afghanistan (Joint Improvised-Threat Defeat Organization 2011). UNMAS also has generic IED awareness materials on its website that could be adopted by a city or country and customized (translated, etc.) as needed (United Nations Mine Action Service 2017a).

Lastly, research has been conducted on trying to prevent the use of different chemicals in IEDs. One resource is a study conducted by the National Academies of Science in the late nineties, titled: Containing the Threat from Illegal Bombings: An Integrated National Strategy for Marking, Tagging, Rendering Inert, and Licensing Explosives and Their Precursors (National Research Council 1998). The study was very comprehensive and provided an overview of the state of the art, research, gaps, and future research directions. Many approaches specifically related to preventing the use of ammonium nitrate in IEDs are being considered as it has been and continues to be the most-used chemical precursor in IEDs (Drummond and Shachtman 2010).

Detection

Perhaps the most researched area in counter-IED efforts is that of detection. Detection techniques almost always rely on some fundamental technology, making them popular with scientists and researchers looking to create the next best detection technique. With the increased scrutiny given to IEDs in the last few decades, detection is the area most likely to be able to be commercialized, leading many technology-driven companies, large and small, to devote resources to detection-based initiatives. Many academic and government labs around the world have also devoted efforts towards fundamental and applied detection-related research.

Given the aforementioned litany of types of IEDs, their components, and situations and environments in which they are used, there exists a need and demand for various types of detection techniques. Different detection methods have different abilities and constraints associated with them. A detection opportunity at an airport security line presents different challenges and needs than it would at the front gate of an embassy. As such, there are many different types of detection techniques, both commercially available and in research and development. Not one technique is going to be able to cover all the detection needs that exist.

When determining which detection technique is going to work best in a given situation there are numerous questions that need to be asked and considered. There are, however, four overarching questions that should always be considered and that can help frame the needs and solutions. These are:

- What is the importance of distance in detecting the explosive threat?
- Does the explosive material itself need to be detected, or just the presence of the threat device?
- Is the purpose / need to detect a trace amount of explosive, or a bulk amount?
- Does the explosive material only need to be detected, or does it need to be identified as well?

Each of these questions helps dictate the needs of the detection method and will help determine which one to choose for a given operational need.

What is the importance of distance in detecting the explosive threat?

The ability to detect an explosive threat with the sensor at a great distance (stand-off) from the threat is the goal. If an explosive can be detected at a distance far enough away that proper countermeasures can be taken before the device can impact its desired target then in many cases the risk to that target, and the detector itself, can be greatly minimized. However, this cannot and will not be a panacea in all situations where explosive-threat detection is needed. Situations where line-of-sight is hindered, spaces are tight, and potential targets cannot be demarcated from an exclusion zone all exist; close-range detection methods are still needed.

What needs to be detected, the presence of a threat or the explosive material itself?

This will be situationally dependent. Detecting there is an explosive threat when its location is unknown is always the priority such that countermeasures can be started. Often the best way to detect an explosive threat is by detecting the explosive material itself, but this is not always true. One example would be a buried landmine or buried IED where detecting the container material, or a disturbance in the earth or road top where the device is buried, is often easier than trying to detect the explosive material in the device. In other situations, such as airport screening, there are many objects and materials present. Therefore, detection of the actual explosive material is desired to decrease false alarms and ensure timely passage of travelers.

Is the purpose / need to be able to detect a trace amount of explosive, or a bulk amount?

Some detection methods require a minimal amount of material to successfully perform detection. Others are more capable of detection of trace amounts. Trace is a term often used but ill-defined. For the purposes of the discussion herein, 'trace' is defined as relating to an amount of material on the order of at most tens of micrograms, or an amount that cannot be seen with the naked eye (situation dependent). 'Bulk' refers to amounts of at least milligrams, going up to hundreds of kilograms. Detecting the presence of explosive residue in or on a vehicle may require a different technique than trying to detect the presence of an IED on a suicide bomber.

Does the explosive material need to be identified in addition to being detected?

The ability to detect an explosive threat is always the first step in a real-time situation where people's lives are at stake. However, sometimes it is desirable to know exactly what explosive is present as this may determine the next steps. For example, if an IED is found and first responders are trying to understand how to move the IED, it could be important to know whether the IED contains an explosive that could be sensitive to movement, such as triacetone triperoxide (TATP). Full identification is the key objective in any sort of forensic situation (covered in a later section).

There are various techniques that exist or could be considered for the detection of explosives and explosive threats. While it is important to know that there are additional techniques by which an explosive threat could be detected that don't rely on detecting the explosive material (such as metal detectors, ground penetrating radar, etc.), only those methods that are specific to detecting the explosive material will be covered herein. Figure 3 shows some of the more widely used detection methods and some specific techniques thereof. They are separated into whether they are applicable to trace or bulk detection, or both.

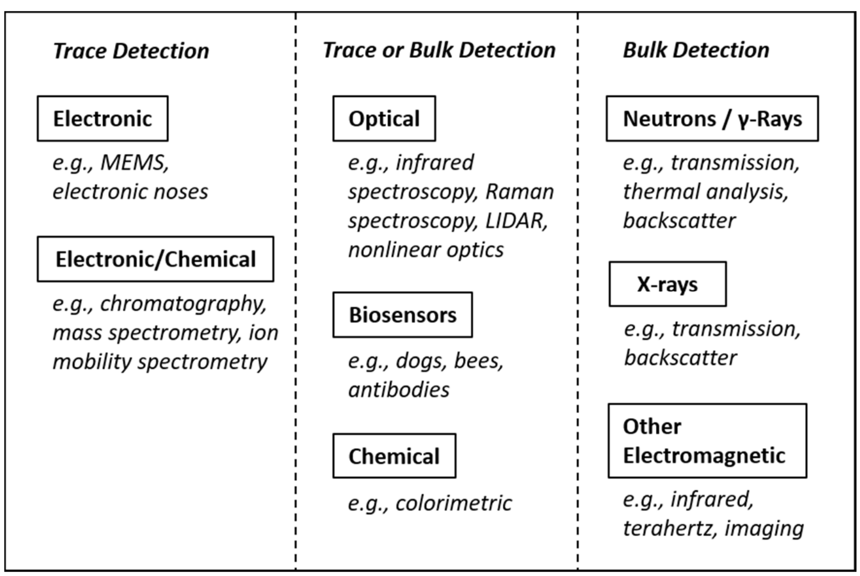

Figure 3. Overarching methods of explosive detection, categorized by applicability to trace or bulk detection, or both.

There are numerous review articles in the published literature that go into details for each of the listed detection methods, and many more (Moore 2007; National Research Council 2004; Gares et al 2016;

Marshall and Oxley 2009). To provide context, however, the different techniques will be briefly described herein. Where possible, recent advances will be mentioned.

Trace Detection Methods

Trace detection techniques tend to be based on established analytical chemistry techniques. Techniques such as mass spectrometry, and chromatography (liquid or gas) have been used in chemistry research for decades, helping to elucidate elemental and molecular information of chemicals and mixtures thereof. As explosives are chemicals, these techniques can be utilized, sometimes with modification, to analyze them. These methods can also be ruggedized and otherwise adapted for use outside of a laboratory environment, where electronic noise, interferents and confusants, and other obstacles to analysis may be present. Microelectromechanical systems (MEMS) and electronic noses also show promise as they tend to be smaller, lower-power alternatives to traditional trace detection methods. While the underlying phenomena of how these methods operate are generally understood, they suffer from inconsistency (especially in real-life environments where interferents and confusants are present) and difficulty in providing exact identification (especially for mixtures).

There are numerous exciting areas of research related to trace detection. One is the continuing push to move traditionally lab-only analysis techniques to the field, and in handheld form. Companies are now offering commercially available, handheld mass spectrometers. While still limited in various ways, these products demonstrate the continuing technical advances that are being made. The next 5-10 years should see these devices continue to evolve and mature. Another exciting area has been that of molecularly imprinted polymers (MIPs). MIPs technology relies on creating polymers that have binding sites that have been imprinted with specific molecules of interest. As such, these materials can be designed to be very specific. The binding event can then be measured as a gain in mass on a sensor chip, or even expressed as a color change in a solution or on a wipe (Lu et al 2015).

Bulk Detection Methods

In addition to needing much more material to sense, bulk techniques often also use methods that require or utilize lots of power, often making their use around people a challenge. An x-ray system used to check baggage, or perhaps a car, for hidden explosive material is not safe for humans, so the material under inspection needs to be separated from any human presence. This often requires time and space. However, the use of lots of power also means bulk techniques can often eschew some of the limitations of trace detection technologies. For example, some bulk detection techniques allow for the detection of a mass of explosive through other materials, whether they be organic or inorganic, on a body or lying buried or otherwise hidden. These techniques are important as the use of PBIEDs and VBIEDs by malefactors continues to increase.

Many bulk detection techniques use different frequencies in the electromagnetic spectrum to interrogate and sense explosives (Figure 4). By measuring transmitted, attenuated or scattered neutrons it is possible to not only image an object but perhaps also provide elemental composition. Due to the penetrating nature of neutrons, techniques involving them have the potential to sense materials that are hidden or not in plain sight. Alternatively, nuclei that are excited by neutrons decay via a gamma-ray mechanism and these gamma rays can be measured. Given that these gamma rays are specific to the nuclear structures they emit from, unique elemental signatures can be obtained (Runkle et al 2009).

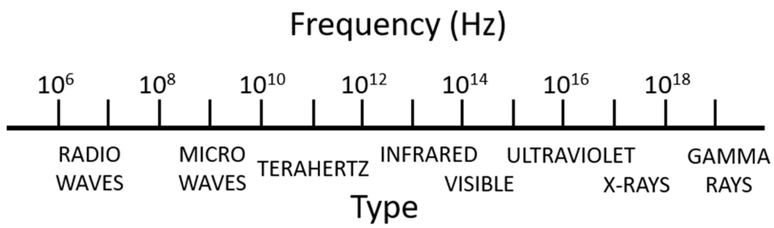

Figure 4. The electromagnetic spectrum and the common names for different regions of frequency.

X-ray techniques allow for the measurement of density of a material. Due to the relative maturity of using x-rays to image objects inside other materials (e.g. bones inside a human body), x-ray machines are used extensively to screen luggage at airports and packages in mail both quickly and reliably. The technique is not specific to certain compounds – densities can be measured but they only give an indication of the elements present, not necessarily the presence of specific molecules. Second, given that x-ray radiation is ionizing, people are not allowed to be present close to the interrogation. Stand-off x-ray techniques are of research interest as they may not be plagued by the same safety issues as current baggage and package scanning equipment (National Research Council 2004).

Methods for Trace or Bulk Detection

There are some methods that can be applied to the detection of trace or bulk explosives. Certain spectroscopic techniques, such as Raman spectroscopy or infrared spectroscopy, are adaptable considering they are line of sight analysis techniques that rely on a surface area of material to analyze. Changing the power of the interrogation laser, the optics used and interrogation, collection and analysis time, can allow for short, medium, or longer-range standoff and/or the ability to detect trace or larger amounts of explosive. For example, Raman spectroscopy has been shown to be effective at sensing explosives at over 100 meters (Gares et al 2016). Raman spectroscopy has been used to detect and identify trace amounts of explosives in fingerprints (Tripathi et al 2011). Other advances in the field include handheld detectors that combine technologies – such as Raman and infrared, or several wavelengths of Raman.

Detecting explosives is challenging. Many explosives have extremely low vapor pressures (parts-per-trillion and lower) and sensing their vapors in real life environments is difficult (Ewing et al 2013). There is, therefore, a large research focus on sampling techniques for trace explosives detection. The National Institute of Standards and Technology has various research endeavors aimed at improving sampling for explosives collection (Najarro 2012). Lastly, any detection technique that requires a sensor other than the naked eye requires algorithms and/or software, and databases, to interpret any collected data as a detection event. The degree of difficulty in this is highly dependent on the detection technique – for some it is trivial, for others the algorithms and databases are critically important and much of the research on the detection technique is spent on the data interpretation piece.

Delay and Protection

Delay refers to the ability to increase the time it takes for a malefactor to carry out an explosive-based attack against a target. Protection refers to the ability to protect would-be targets from the effects of an explosion. Measures that can increase a malefactor's timeline in carrying out an explosive attack are also important in aiding in detection and response. For example, increasing the time it takes to transport an IED to a desired target location allows for more time and opportunity to detect that IED or the actions associated with transporting it. This is the impetus for ensuring a proper amount of open space between an entrance to a military base or embassy and any buildings that may be targets or contain targets. Oftentimes a perimeter boundary is utilized with a long and/or indirect path to gain access to inner protected areas. This artificially created delay is crucial for providing more time to interrogate a suspicious person or vehicle with detection technologies and then allows for a suitable response, if needed, before targets are threatened. In fact, overt detectors, whether they be cameras, portals, or something else, can also act as methods of delay as a malefactor may be forced to rethink their path or plan to try to evade detection. While there isn't as much research in terms of delay technologies, there are always ongoing regulations and policies that are created and considered regarding the most effective methods to use for a given situation.

One excellent resource for understanding physical protection strategies in relation to buildings and infrastructure is the National Institute of Building Sciences (Smilowitz 2016). There are four basic physical protection strategies to resist explosive threats:

- Establishing a perimeter that is secure
- Mitigating hazards resulting from debris
- Preventing progressive collapse
- Isolating internal threats from occupied spaces

Other considerations include the tethering of non-structural components and protecting emergency services. It is important to first define the design threat as this understanding of the explosive threat and what needs to be withstood is critical to properly designing and implementing the physical protection strategies. The U.S. DHS Federal Emergency Management Agency (FEMA) has a publicly available resource that assists people in determining the threat identification and rating, conducting vulnerability and risk assessments and then considering options for mitigating potential terrorist attacks against buildings (Federal Emergency Management Agency 2005).

Vehicles must also be protected, in large part to protect the people inside of them. This is true mainly in military applications, where soldiers can constantly be in vehicles to complete their missions. One example of vehicle protection is that of the mine-resistant, ambush protected (MRAP) vehicle. MRAP technology was first developed in South Africa in the 1960s to assist armed forces in South African nations in combatting IED threats. Elevating the chassis and creating a V-shaped hull on a military vehicle was shown to help direct mine blasts out and away from the vehicle. The US military became heavily interested after seeing the effects of buried IEDs on its forces in the wars in Iraq in Afghanistan and started researching and producing the next generation of MRAP vehicles in the early 2000s (Blakeman et al 2008). MRAPs are now a mainstay in U.S.-based operations overseas. Vehicles may also have extra protection against blast effects due to the materials or cargo they have inside of them. Tankers that transport flammable or otherwise hazardous chemicals, radiological materials, and/or large amounts of money may all need to be protected more heavily than standard trucks.

While protecting buildings and vehicles will also hopefully prevent major harm to people inside them, more specific and personal protection needs to be considered when people don't have the protection of a structure or vehicle. Explosives ordnance disposal (EOD) and bomb technicians wear specially designed bomb suits that help protect against fragmentation and reduce the effects of the air blast pressure. Specially designed outer- and undergarments have even been designed to help protect military personnel from the blast effects from buried IEDs. The garments help protect the pelvic region against fragmentation propelled upward and have been shown to be effective in helping minimize injury (Brook 2012). Research continues in the development of lightweight, effective means to protect EOD, bomb technicians and other military personnel from the effects of an explosion.

Response and Analysis

This last section provides an overview of the approaches taken by first responders and others when responding to explosive threats, either pre- or post-blast. In addition, the utility and importance of analysis of explosive threats, to go beyond initial detection of a device, is discussed.

A first responders' ultimate goal in responding to an explosive threat is to safeguard life, whether that be in preventing injury (in the case of response to a suspected or found explosive threat) or assisting those that are injured after an explosion (post-blast scenario). First responders are therefore often comprised of law enforcement and medical professionals. In performing their duties, however, they often rely on additional expertise to assist. This additional expertise tends to center around the technical ability to dispose, disrupt or render the explosive threat(s) safe. It is these technical experts that focus on ensuring the explosive threat can be deemed "safe" and then look to collect as much information possible to assist in the analysis of the explosive threat, either pre- or post-blast, as the situation allows. The US Department of Justice has a guide that assists in the response and investigation of an explosive threat (U.S. Department of Justice 2000)

In a pre-blast scenario, first responders' main goal is to protect people from the threat. This is usually accomplished with evacuation procedures or ensuring there is proper distance and shielding in-between those in danger and the explosive threat. In addition, efforts may be made to physically move the threat or decrease the threat's damage potential by encasing or covering it to minimize the effect of its explosive output on the surroundings.

The analysis of a pre-blast explosive threat often starts with the stressful and dangerous operation of rendering the explosive device safe. This should only be conducted by trained specialists, often referred to as bomb technicians or explosives ordnance disposal (EOD) technicians. Oftentimes trained experts use robots and other remote means to render an explosive device safe before they come within physical proximity of the device. There are numerous tools that are used to accomplish the tasks involved in rendering an explosive device inert, or safe. Some of the types of tools used can be found in online searches.

Once the threat has been rendered safe, forensics teams can then start their analysis. Some of this is done at the scene, as possible, but most of the evidence is instead collected and sent to a lab for analysis on specialized equipment by trained experts. The Terrorist Explosive Device Analytical Center (TEDAC) was established in 2003 under the auspice of the FBI to be the single interagency organization to analyze IEDs in the United States (Terrorist Explosive Device Analytical Center 2017). They use different forensics techniques to determine the composition of an IED, information about its fate and transport, and even information relating to the bombmakers (e.g. DNA or latent fingerprints). TEDAC has also provided assistance to foreign governments who request support in analyzing explosives threats that have been found in their country.

The response and analysis of a post-blast event poses different challenges than that of a pre-blast event. While there is often less danger to the first responders and technical experts on hand, oftentimes there are time sensitive casualties that take precedence. There may also be additional hazards present, such as decomposed or unstable buildings or infrastructure, additional explosive devices or radiological or chemical hazards. For the analysis teams, it is more difficult to find and collect evidence in a post-blast event. It is critical to gain an understanding of the factors that contributed to the blast, the materials used in the blast (if relevant) and those who were responsible for the blast (if relevant). One key question in any post-blast investigation is whether the explosion was an accident or deliberately detonated.

As with pre-blast situations, every aspect of the materials that comprise the explosive device are searched for and analyzed. Oftentimes fragments of an exploded device will be left intact, to include switches, wiring, timers, circuit boards, power sources, etc. Video footage may be able to provide clues as to what fragments found in a post-blast situation may relate to the device, or where those fragments might have ended up. In addition, residue from the main charge explosive or booster/initiator will often be present. Oftentimes there are large amounts of confusants and interferents in post-blast situations, making the sampling and analysis even more challenging.

There is ongoing research and evaluation of next-generation approaches to first responder tactics and tools and explosive threat analysis techniques, equipment and methods. Many of this research is closely guarded by governments, military and private companies as these explosives countermeasures are critical to ensuring peoples' safety and in counterterrorism efforts. As such, it is important that malefactors do not know the full capabilities that first responders, bomb technicians, and forensic analysts possess such that they cannot gain an advantage in a given situation.

Training of first responders and EOD/bomb techs is an ongoing endeavor, with numerous local, state and federal training programs across multiple agencies, as needed. It is estimated that there are ~3000 bomb disposal technicians (not to include military EOD personnel) in the U.S., representing over 450 different agencies (Laska 2016). There are numerous training courses that are offered at various levels of the government to ensure the continual readiness and expertise needed to appropriately respond to explosive threats. The FBI offers multiple courses and training programs (Hazardous Devices School, Large Vehicle Bomb Post-Blast Crime Scene School, Post-Blast Investigation Training). The ATF also has its Arson & Explosives Training Programs. DHS uses the Energetic Materials Research and Testing Center, affiliated with New Mexico Tech, to offer trainings in Incident Response to Terrorist Bombings and Prevention and Response to Suicide Bombing Incidents (Laska 2016). The U.S. Office for Bombing Prevention offers many courses that pertain to IED and related threats (Office for Bombing Prevention 2017). The Department of State also has its Office of Antiterrorism Assistance that provides training on explosives threats and response to smaller, less advanced nations (United States Department of State 2016).

Summary and Outlook

IEDs and other explosive threats have become one of the gravest challenges the world faces in terms of security and terrorism. The precursor materials and information needed to make IEDs and other explosive threats are not difficult to obtain and there are many variations of explosive threat these days, making a singular approach to countering them impossible.

Given the timeline of a terrorist attack cycle, there are various responses and actions that can be taken to try to counteract the threat. Broadly speaking, these are deterrence, prevention, detection, protection and response, or some variation thereof. Each of these are an important aspect in the fight against explosive threats and only by researching and developing means to implement each can a holistic, successful counter-explosive threat strategy be developed and implemented. It will be important for governments to continue to invest in counter-explosive threat solutions moving forward. Recommendations of important areas of research and research directions have been developed to aid in suitable paths forward (National Research Council 2007, 2008; Subcommittee on domestic improvised explosive devices 2008). Themes such as anti-radicalization and awareness campaigns, next-generation detection techniques, better training for first responders, and advanced forensics capabilities will all be crucial to continue to effectively counter existing and emerging explosives threats.

There are numerous agencies and entities that fund, conduct and advance research and development to counteract the threat from explosive attacks; and counter-IED policies, regulations, technology and solutions are continually evolving and improving. At the same time, the tactics and techniques used by malefactors are also evolving; they are continually looking for new methods to avoid suspicion and detection and increase lethality. The threat from explosives will continue to be a major concern for the foreseeable future and the race to stay on par with those wishing to cause harm will be an ongoing challenge.

References

Blakeman ST, Gibbs AR, Jeyasingam J (2008) Study of the mine resistant ambush protected (MRAP) vehicle program as a model for rapid defense acquisitions. Dissertation, Naval Postgraduate School

Brook TV (2012) Protective undergarments cutting IED-related wounds. USA Today. https://www.usatoday.com/story/news/world/2012/12/11/blast-boxers-saving-lives-afghanistan-casey/1758389/. Accessed 15 Jan 2018

Chicago Project on Security & Threats (2017) Suicide attack database. http://cpostdata.uchicago.edu/search_new.php. Accessed 18 Jan 2017

Coggeshall JL (1997) The fireship and its role in the royal navy. Dissertation, Texas A&M University

Conflict Armament Research (2017) Islamic state's multi-role IEDs. www.conflictarm.com/download-file/?report_id=2490&file_id=2492. Accessed 18 Jan 2018

Cullison A, Trofimov Y (2010) Karzai Bans Ingredient of Taliban's Roadside Bombs. The Wall Street Journal. https://www.wsj.com/articles/SB10001424052748703822404575019042216778962. Accessed 14 Jan 2018

Dathan J (2017) Explosive truths: monitoring explosive violence in 2016. Action on Armed Violence. https://aoav.org.uk/wp-content/uploads/2017/05/AOAV-Explosive-Monitor-2017v9.pdf. Accessed 17 Jan 2018

Dettmer J (2015) Activists: Syria's Assad adds 'elephant rockets' to arsenal. VOA news. https://www.voanews.com/a/syria-assad-elephant-rockets/2826391.html. Accessed 18 Jan 2018

Drummond K, Shachtman N (2012) Pentagon looks to sabotage Pakistan's bomb supply. Wired. https://www.wired.com/2012/01/sabotage-pakistan-bomb-supply/. Accessed 19 Jan 2018

Edgar C (2015) Empowering Afghan Citizens to Counter IED Threats. https://www.defense.gov/News/Article/Article/616344/empowering-afghan-citizens-to-counter-ied-threats/. Accessed 12 Jan 2018

Ewing RG, Waltman MJ, Atkinson DA, Grate, JW, Hotchkiss PJ (2013) The vapor pressures of explosives. TrAC 42:35–48. doi:10.1016/j.trac.2012.09.010

Federal Emergency Management Agency (2005) Risk Assessment: A how to guide to mitigate potential terrorist attacks against buildings

Gares KL, Hufziger KT, Bykov SV et al (2016) Review of explosive detection methodologies and the emergence of standoff deep UV resonance Raman. J Raman Spectrosc 47:124–141. doi:10.1002/jrs.4868

Harrell B (2017) The private sector is the key to success for the Department of Homeland Security. https://www.csoonline.com/article/3161793/security/the-private-sector-is-the-key-to-success-for-the-department-of-homeland-security.html. Accessed 14 Jan 2018

Homeland Security Presidential Directive 19 (2007) Combating Terrorist Use of Explosives in the United States

International campaign to ban landmines – cluster munition coalition (2017) Landmine monitor 2017. http://the-monitor.org/media/2615219/Landmine-Monitor-2017_final.pdf. Accessed 14 Jan 2018

Ismay J, Gibbons-Neff T, Chivers CJ (2017). How ISIS Produced Its Cruel Arsenal on an Industrial Scale. The New York Times. https://www.nytimes.com/2017/12/10/world/middleeast/isis-bombs.html. Accessed 18 Jan 2018

Joint Improvised-Threat Defeat Organization (2011) Homemade explosive (HME) / bulk explosive (BE) recognition guide. https://www.jieddo.mil/content/docs/HMEGuide_Final_v3_HR_U.pdf. Accessed 19 Jan 2018

Kaaman H (2017) The evolution of suicide car bombs examined. Action on Armed Violence. https://aoav.org.uk/2017/evolution-suicide-car-bombs/. Accessed 18 Jan 2018

Laska, PR (2016) Bombs, IEDs and explosives: identification, investigation, and disposal techniques. CRC Press

Lu W, Xue M, Xu Z et al (2015) Molecularly imprinted polymers for the sensing of explosives and chemical warfare agents. Curr Org Chem 19:62–71

Marshall M, Oxley JC (eds) (2009) Aspects of explosives detection. Elsevier, New York

Moore DS (2007) Recent advances in trace explosives detection instrumentation. Sens imaging 8:9–38. doi:10.1007/s11220-007-0029-8

Najarro M, Gillen G (2012) NIST Explosives Test Bed. https://www.nist.gov/sites/default/files/documents/oles/5-Najarro_Marcela-NIST-Trace-Explosives-Test-Bed-2.pdf. Accessed 18 Jan 2018

National Academies of Sciences, Engineering, and Medicine (2017) Reducing the Threat of Improvised Explosive Device Attacks by Restricting Access to Explosive Precursor Chemicals. The National Academies Press

National Research Council (2008) Disrupting Improvised Explosive Device Terror Campaigns: Basic Research Opportunities: A Workshop Report*.* The National Academies Press

National Research Council (2007) Countering the Threat of Improvised Explosive Devices: Basic Research Opportunities: Abbreviated Version*.* The National Academies Press

National Research Council (1998) Containing the Threat from Illegal Bombings: An Integrated National Strategy for Marking, Tagging, Rendering Inert, and Licensing Explosives and Their Precursors*.* The National Academies Press

National Research Council (2004) Existing and Potential Standoff Explosives Detection Techniques. The National Academies Press

Office for bombing prevention (2017) Counter-IED resources guide. https://tripwire.dhs.gov/IED/resources/docs/OBP_Counter-IED_Resources_Guide.pdf. Accessed 7 Jan 2018

O'Haver H (2016) How 'if you see something, say something' became our national motto. The Washington Post. https://www.washingtonpost.com/posteverything/wp/2016/09/23/how-if-you-see-something-say-something-became-our-national-motto/?utm_term=.df074b8026e3. Accessed 12 Jan 2018

Presidential Policy Directive 17 (2013) Countering Improvised Explosive Devices

Runkle RC, White TA, Miller EA et al (2009) Photon and neutron interrogation techniques for chemical explosives detection in air cargo: a critical review. Nucl. Instr. Meth. Phys. Res. A 603:510–528. doi:10.1016/j.nima.2009.02.015

Smilowitz R (2016) Designing buildings to resist explosive threats. National Institute of Building Sciences. https://www.wbdg.org/resources/designing-buildings-resist-explosive-threats. Accessed 18 Jan 2018

Subcommittee on domestic improvised explosive devices (2008) Research challenges in combatting terrorist use of explosives in the United States. Subcommittee on domestic improvised explosive devices. https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/nstc-domestic-ied-2008.pdf. Accessed 7 Jan 2018

Terrorist explosive device analytical center (2017). https://www.fbi.gov/services/laboratory/tedac. Accessed 16 Jan 2018

Thapliyal D (2016) Turkey's nitrate ban sends shockwaves across fertilizer market

The Express Tribune (2017) Public awareness, education on IED blasts imperative to save lives. https://tribune.com.pk/story/1343894/public-awareness-education-ied-blasts-imperative-save-lives/. Accessed 12 Jan 2018

Tripathi A, Emmons PG, Wilcox PG et al (2011) Semi-automated detection of trace explosives in fingerprints on strongly interfering surfaces with Raman chemical imaging. Appl. Spectrosc. 65(6):611–619. doi:10.1366/10-06214

United Kingdom Home Office (2016) Guidance: licensing for home users of poisons and explosive precursors. https://www.gov.uk/government/publications/licensing-for-home-users-of-explosives-precursors/licensing-for-home-users-of-poisons-and-explosive-precursors. Accessed 15 Jan 2018

United Nations (2017a) United Nations Office of Counter-Terrorism. http://www.un.org/en/counterterrorism/. Accessed 18 Jan 2018

United Nations (2017b) United Nations Office of the Secretary-General's Envoy on Youth. http://www.un.org/youthenvoy/. Accessed 18 Jan 2018

United Nations Mine Action Service (2017a) IED awareness. http://www.mineaction.org/unmas/ied-awareness. Accessed 14 Jan 2018

United Nations Mine Action Service (2017b) United Nations Mine Action Service improvised explosive device lexicon. http://www.mineaction.org/sites/default/files/publications/UNMAS%20IED%20Lexicon.pdf. Accessed 7 Jan 2018

United States Department of Justice (2000) A guide for explosion and bombing scene investigation. U.S. Department of Justice. https://www.ncjrs.gov/pdffiles1/nij/181869.pdf. Accessed 7 Jan 2018

University of Maryland (2017) National Consortium for the study of terrorism and responses to terrorism (START). http://www.start.umd.edu/. Accessed 18 Jan 2018

U.S. Department of Homeland Security (2016) Ammonium Nitrate Security Statute and Regulations. https://www.dhs.gov/ammonium-nitrate-security-statutes-and-regulations. Accessed 14 Jan 2018

U.S. Department of Homeland Security (2017a) Bomb-making materials awareness program (BMAP) https://www.dhs.gov/bmap. Accessed 14 Jan 2018

U.S. Department of Homeland Security (2017b) Chemical Facility Anti-Terrorism Standards (CFATS). https://www.dhs.gov/chemical-facility-anti-terrorism-standards. Accessed 14 Jan 2018

U.S. Department of Homeland Security (2017c) If you see something, say something ™. https://www.dhs.gov/see-something-say-something. Accessed 14 Jan 2018

U.S. Department of State (2016) Antiterrorism Assistance Report 2016. https://www.state.gov/documents/organization/274112.pdf. Accessed 16 Jan 2018

World Customs Organization (2013) Programme Global Shield brochure. World Customs Organization. http://www.wcoomd.org/en/topics/enforcement-and-compliance/activities-and-programmes/security-programme/programme-global-shield.aspx. Accessed 14 Jan 2018

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