Threat Detection Technologies Covering an Extended Range of Eventualities

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Abstract. Threats may be originated from more than just explosives. Therefore, threat detection cannot be confined to tracing such substances only. The terrorist attack in the Tokyo's underground system with the nerve gas sarin in 1995 has already demonstrated that there are other means of threat. Hidden noxious agents like this need to be detected with the same urgency before they may cause harm. The technological challenge here is to apply adequate sensors. The existing range of warfare substances comprises various different chemicals that may require distinct detection methods. Like explosives need a fuse to detonate, toxic substances have to be applied in some way in order to become active, i.e. they have to be evaporated, atomised or otherwise distributed to be inhaled or to come in touch with the skin or the eyes. Even worse, it cannot be excluded any more that harmful substances may be combined with explosives like in dirty bombs. In addition to the enhanced threat, this at least complicates any rendering safe procedures.

Most closely related non-destructive testing tasks that might be of interest in this context may be the detection of leakages as well as the assessment of efficiency and reliability of the applied methods. Multi-gas sensors have been developed and are being tested particularly for hazardous and toxic gases and vapours and could be used for preventive scanning. Furthermore, remote-controlled spectroscopic methods can be useful tools to identify some of those substances. As in the case of the inspection of unexploded ordnance (UXO) or of improvised explosive devices (IEDs) radiological technologies are helpful to detect setups capable to release suspicious or even noxious substances into the air.

Introduction

A week, or even a day without a report on bombing in the news has become rare. As a consequence, detecting a threat before it causes harm is a prominent public interest. On the other hand, we are also in the middle of a cat-and-mouse chase to hide bombs and booby traps and to detect them on time. Moreover, explosives are not the only means of threat, as sadly proven by some spectacular incidences. It was on 7th September 1978 when the Bulgarian dissident Georgi I. Markov was attacked with the so-called "Bulgarian umbrella". He died of ricin intoxication three days later. Amounts of less than a milligram are absolutely fatal. On 20th March 1995, members of the religious group Aum Shinrikyo released sarin in an attack in the underground railway of Tokyo. This chemical warfare agent (CWA) was also employed in the Iran-Iraq war 1980-1988. It is not quite clear what agent has been used in the incident in the musical theatre in Moskow on 26th October 2002 where 123 people died and 650 survived. It may be worth to mention in this context that some groups such as the "Animal Liberation Front" (ALF) in Great Britain have specialised themselves applying incendiary devices.

So there is a scaring variety of threats one has to be aware of. Alternatively to identify threatening substances directly, there are ways to detect secondary indications such as devices necessary to apply certain agents.

1. Identifying the threat

1.1 Types of Threat

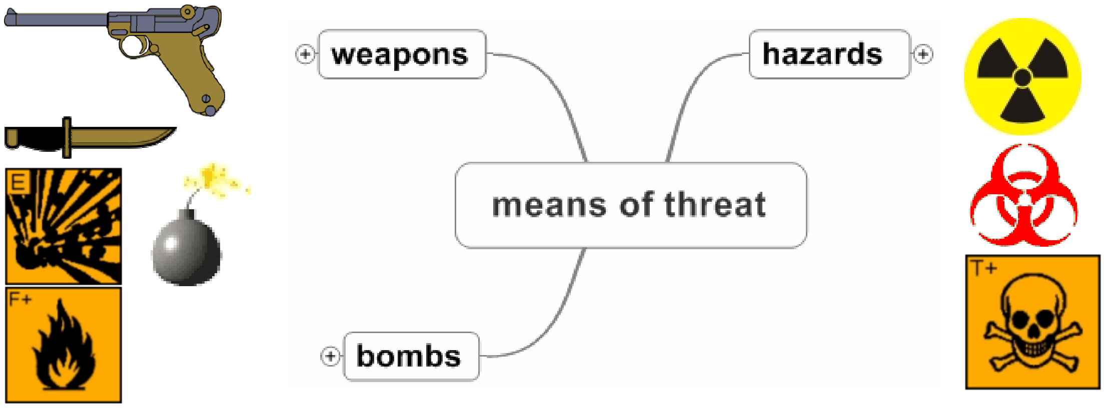


Fig. 1: Kind of threats

Since there are numerous threats, the ones that have been already encountered and further ones nobody except the initiator(s) may have the slightest idea of, a more systematic approach is assumed to be helpful to identify them and consecutively the attributes for detection. Fig. **1** illustrates the categories we are dealing with when talking about threats: weapons which comprise fire-arms and any kind of blades, such as daggers, bombs loaded not only with explosives but also with flammables such as in Molotov cocktails and last not least all the dangerous substances and materials suitable to exert threats on humans.

1.2 Weapons and Bombs

Weapons and any kind of bombs are obviously the most common means of threat, just watching the news providing ample information. Most weapons are detectable by metal detectors, but the existence of ceramic knifes e.g. should be kept in mind in this context. However, there are numerous ways to hide weapons, a matter that will not be discussed in detail here. Fig. **2** lists some possible places just to make aware where threats could be encountered from. It is a central concern of public security measures to protect the possible targets of terrorist and criminal attacks, as there are all kind of crowded public places and facilities and large public gatherings but also essential parts of infrastructures, not to forget that the latter was a speciality of the IRA.

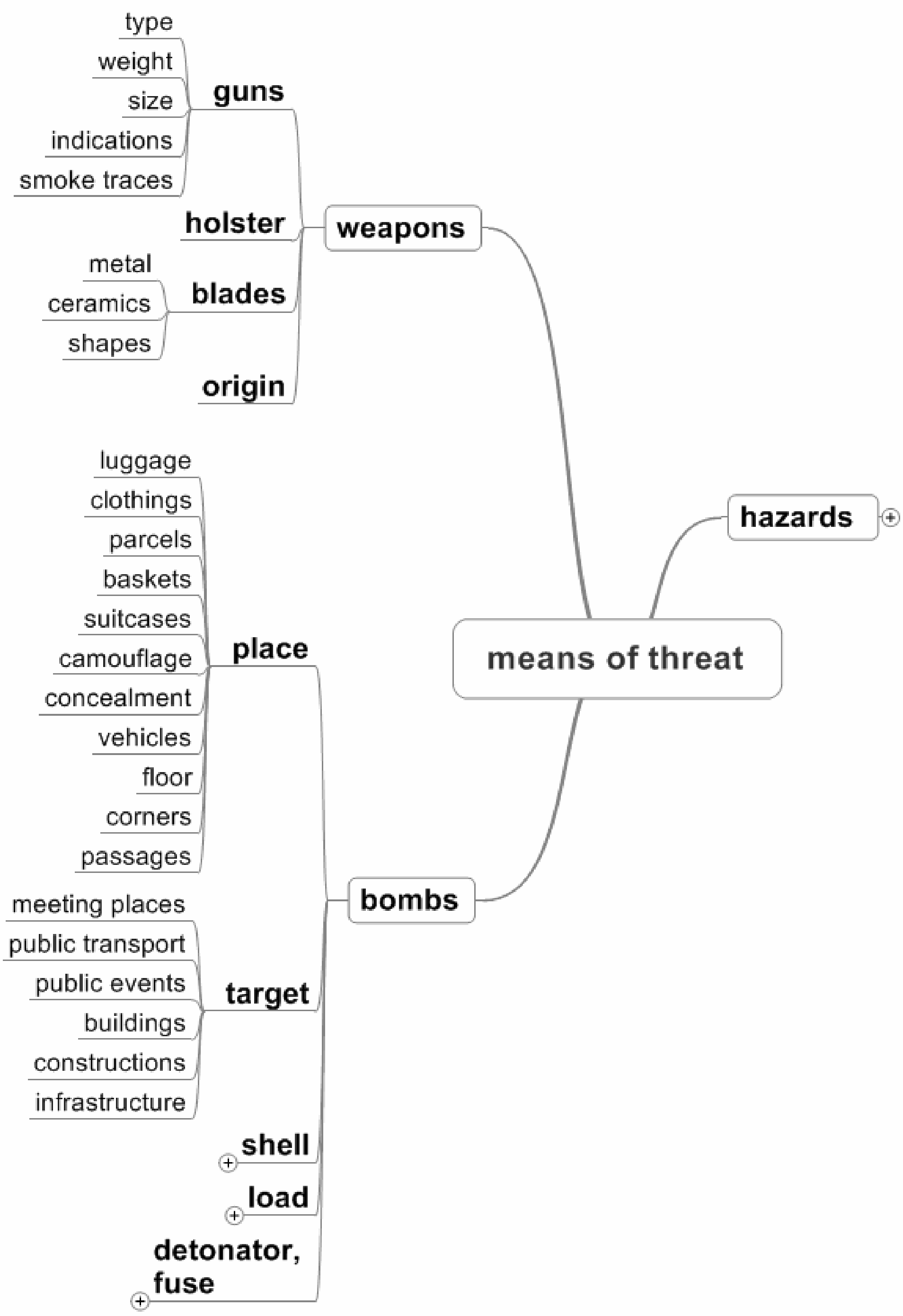


Fig. 2: Weapons and bomb locations.
The places where bombs may be found as well the targets have certainly a lot common with those of weapons.

1.3 Parts and Properties of Bombs

Bombs include not only grenades, ordnance, mines and other ammunitions but also improvised explosive devices which do not have any blueprint of their construction. Fig. **3** should demonstrate the vast range of possibilities how a bomb could be designed and what it might contain in addition to the explosive and the fuse. Even the range of possible explosives exceeds the range of what usually constitutes the military arsenal. In particular, peroxides not containing any nitric oxide which is typical for many explosives particularly in the military environment have played a saddening role like rather recently in the London attack on 7th July 2005. One reason of the occurrence of such substances certainly is the fact that they can be easily home made with ingredients readily available in any chemist shop. In many cases, the effect of a blast is intended to be increased by several additions such as metal scrap (shrapnel effect) or radioactive substances ("dirty bomb"). In cases of suspect objects, it is essential to identify the presence of an explosive.

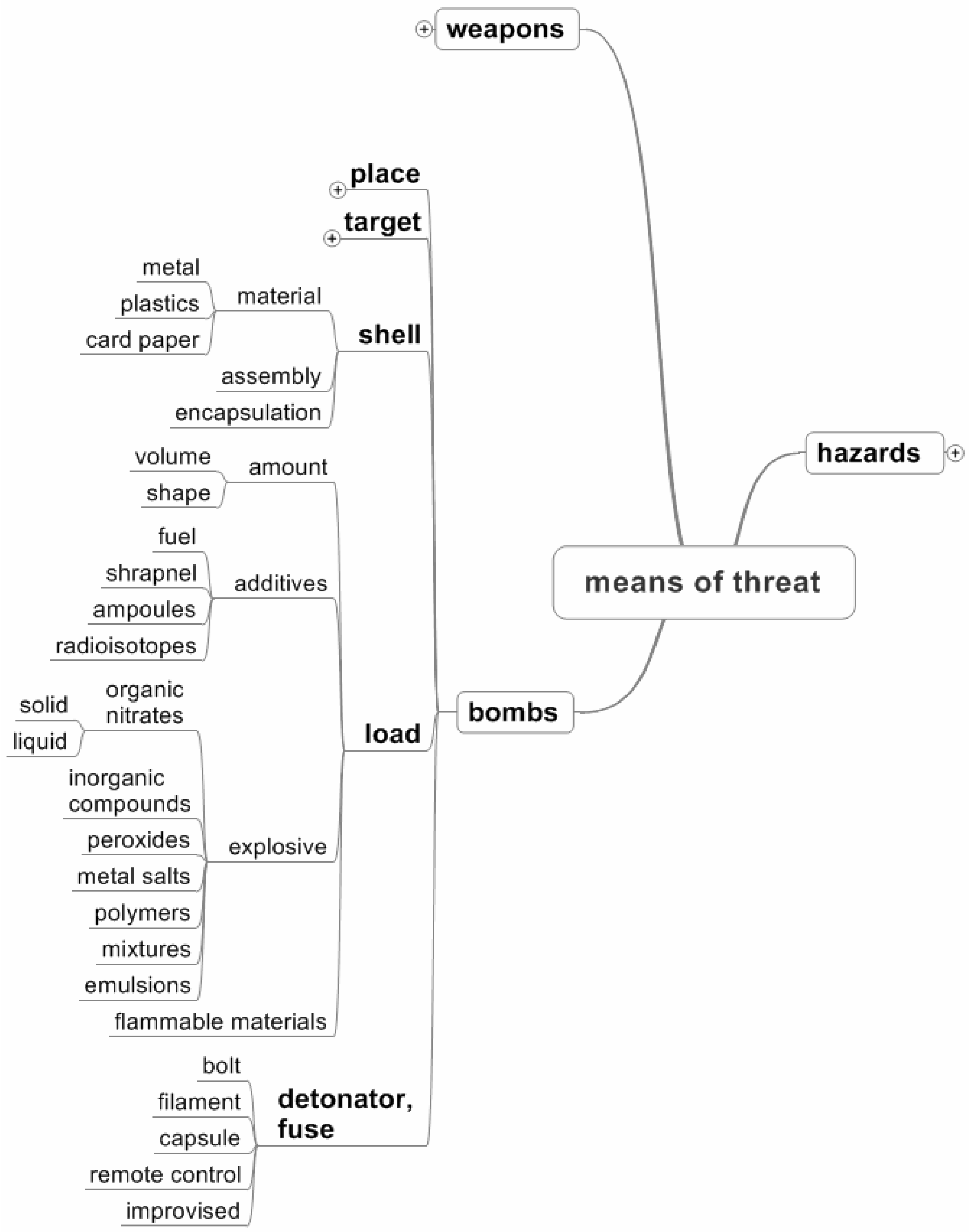


Fig. 3: Essential and intensifying parts of bombs

1.4 Hazardous Materials and Agents

The range of hazardous materials is scaring as they include all the potential and partly known weapons of mass destruction, i.e. the chemical, biological, radioactive and nuclear (CBRN) warfare agents as listed in Fig. **4**. Nuclear and radioactive threats can be identified by their characteristic radiation. However, this is not always easy to detect as in cases of some α- or β-emitters which can easily be shielded. The problem with detectability is even worse with biological agents because they are already active in tiny and hardly detectable amounts. But they can play a role as demonstrated by the ricin attack on a Bulgarian dissident in London in 1978 ("Bulgarian umbrella"). At the time being, it is highly questionable to pay less attention on the detection of biological threats with the arguments of not having a chance on one hand and it would be unlikely that someone would not have the facilities, the knowledge and resources or be simply afraid of handling such material on the other hand. A promising approach to detect realistically such threats would be to identify typical tracing substances as calcium dipicolinate of bacterial spores.

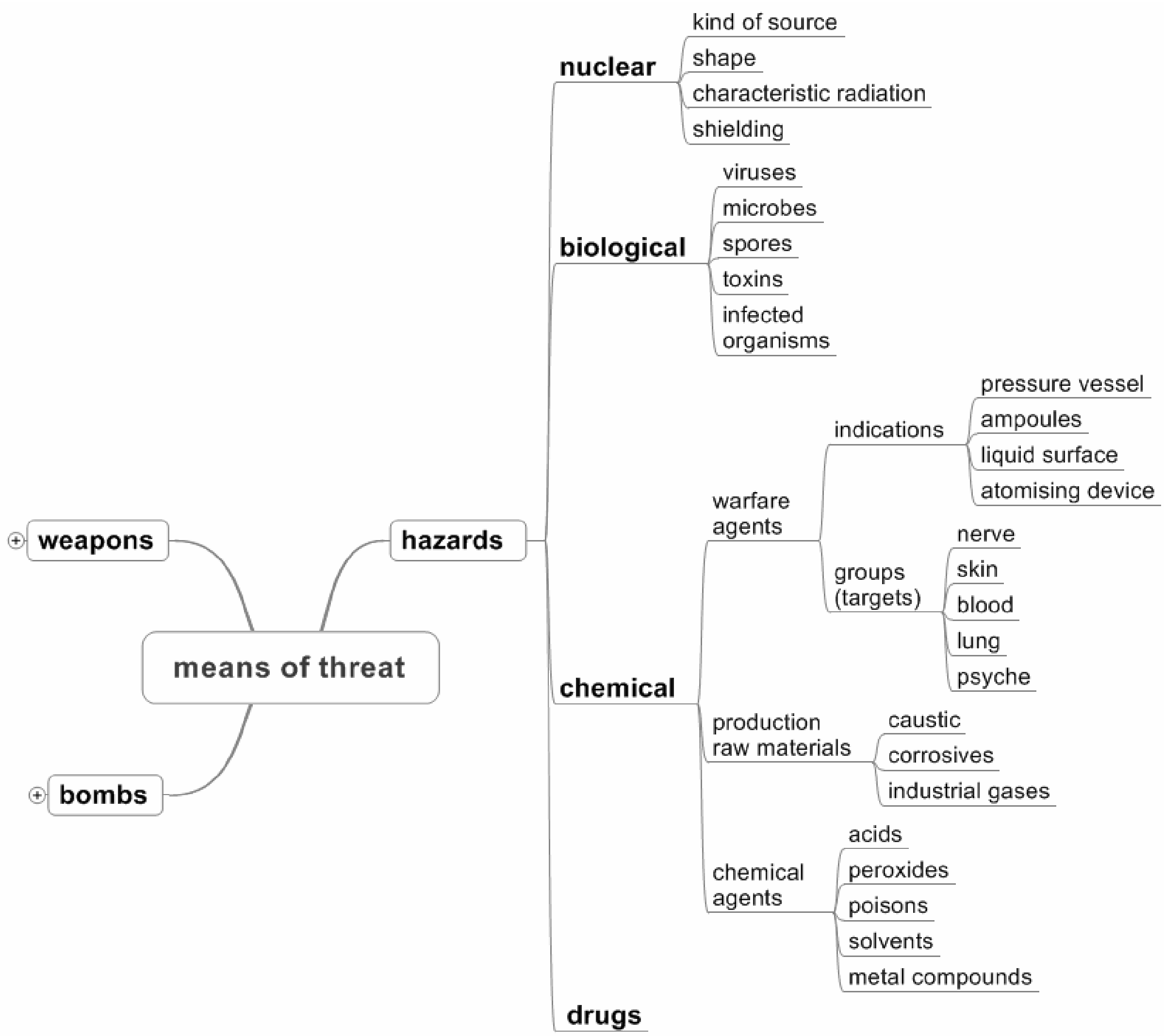


Fig. 4: Hazardous materials and agents as means of threat

Chemical warfare agents have an inglorious history since their first deployment in the World War I and the development of organophosphates, e.g. sarin. Such substances have been involved in terrorist attacks as in Tokyo's underground on 20th March 1995 or in the Iran-Iraq war. Other developments are equally of concern, if not scrupulous, such as that of incapacitating agents like 3-quinulidinyl benzilate (BZ). All these substances might be detectable as traces due to leakage, by neutron activation analysis or indirectly by the presence of adequate containers, of devices to distribute the agent or of liquid surfaces in a radiographic image. In any case of criminal or terroristic assaults the possibility should never being excluded that readily available aggressive chemicals could also being involved. It would go too far in this context to discuss drugs, but in this area, the customs and excise authorities (e.g. HMCE) would certainly be able to assist in identification.

2. Detecting the Threat

2.1 Detection as the First Step in Counteractions

Fortunately, the public is not defenceless against those threats since numerous detection technologies are available nowadays and even more are currently under development. However, none of them is perfect and capable to detect any threat in an absolutely reliable manner. This – as well as the vast range of various ways to threaten peoples' life and health as shown above – justifies the existence and further developments of different technologies even aiming at the same sort of threat. A description of all methods available easily could fill volumes so it is attempted to give a (more or less) systematic overview in Fig. **5**. The classification of technologies in this sketch also includes some close relationships between them indicated by the dotted blue arrows as they cannot be strictly separated, neither with respect to their principle nor in their practical application. As compared to previous suggestions of technologies with a potential in mine detection [1], the broad scale of threats that need to be taken into account requires even a larger "toolbox" as a reply to this challenge.

It would be more than confusing to try assigning certain technologies to the different sorts of threats discussed above since the majority of them can be used multiply. The utmost important feature of threat detection is observation, albeit directly or with the aid of analytical instruments or spectrometers. A technical device delivers an indication e.g. on an optical display that needs correct interpretation. Beside the visual perception nature has provided us with senses of smelling, sound, taste and touching. All the technologies listed here could be regarded as additional sensor or image intensifiers to realise threats before it is too late.

Starting with a kind of threat most difficult to detect, the biological are the ones of highest concern. The simplest one, and perhaps still one of the most efficient ones, is realising symptoms in all living beings around us. Sudden signs of sickness or the observation of dying birds could be such a fatal indication for a biological warfare agent. However, security means to detect the threat as early as possible to allow effective counteractions. Therefore, a number of different sensors are introduced to detect a variety of substances, chemical agents, explosives or even drugs. One of the most advanced technologies even available in handheld devices is ion mobility spectrometer (IMS) where particles are ionised and discriminated by their migration velocity in an electrical field [2]. Other methods are based on molecular imprinted polymers (MIP, see below), quenching of fluorescence or flame ionisation detectors (FID). Classical separation techniques like high performance liquid chromatography (HPLC), gas-chromatography/mass-spectrometry combinations (GC/MS) or electrophoresis are suitable to identify a range of different species but are combined with larger instrumentation. It is quite usual to collect samples of solid traces by wiping surfaces with adsorbing filter paper or cotton. Whenever dealing with low concentrations sample trapping by accumulation on adsorptive surfaces followed by pulsed desorption can be a valuable initial step in different analytical procedures. In case of biological recombinant materials, as it is present in any living cell, amplification by the polymerase chain reaction (PCR) is a standard method in any molecular biology laboratory.

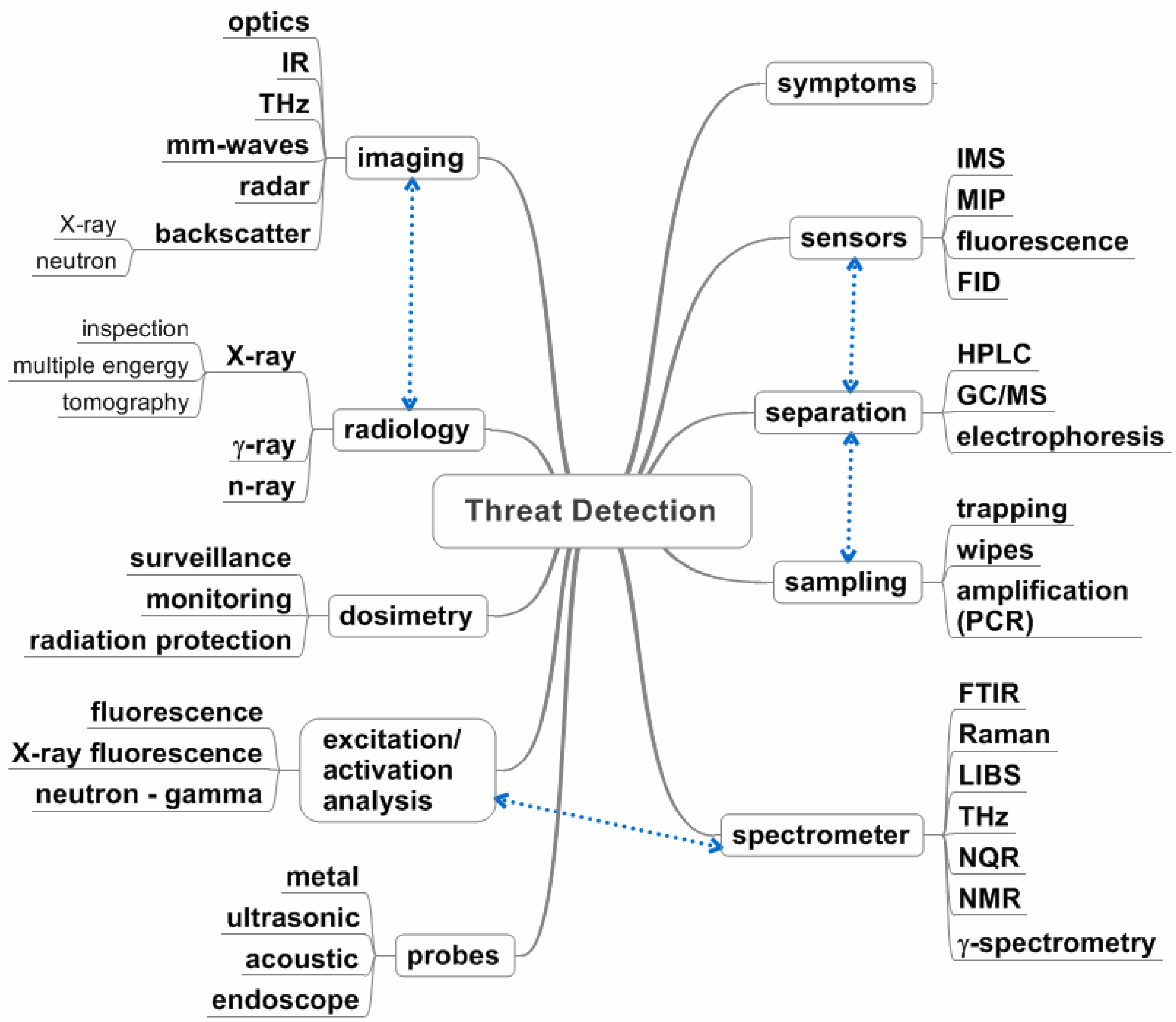


Fig. 5: An overview of threat detection technologies

Spectrometry predominantly is a tool to characterise chemical substance, some are well introduced in laboratories (Fourier transformed infrared (FTIR), nuclear magnetic resonance (NMR)), others already available for outdoor applications (Raman, laser induced breakdown spectrometry (LIBS), γ-spectrometry), and further ones are still in development (e.g. terahertz (THz), nuclear quadrupol resonance (NQR)). Closely related are activation analysis methods such as neutron – prompt and delayed gamma analytic spectrometry or, in a broader sense, optical and X-ray fluorescence methods where electrons are excited by radiation. A detailed description of all these technologies would easily go beyond the scope of this contribution particularly since these are laboratory techniques in the first place rather than for use in field applications at the present stage of development. However, some of them may well have a potential to be applied in threat detection, such as NQR and THz in detecting some explosives.

Probably the most frequently used detection technology are found in metal detectors, either in passenger controls in airports or in mine detection on the fields. Visual inspection by endoscopy and acoustic probing are employed only at certain critical points or on request and ultrasonic testing still is a domain of non-destructive testing in solid materials. A real potential to detect threats is gaining insight into suspected objects using radiation capable to penetrate totally (radiology) or at least some superficial layers to disclose hidden items (imaging). These two areas cannot be separated strictly since some sort of radiation is always involved. Radiographic inspection including its advanced forms such as multiple energy technologies or tomography are based on total penetration of the specimen, regardless if X-, gamma- or neutron rays are employed. However, these techniques essentially need an access from at least two sides, from the front and the back. The advantage of methods utilising back scattered radiation do not have that restriction. It is noteworthy that not only ionising radiation is being used but also the spectrum between visible light and radar, namely infrared (IR), terahertz (THz) and millimetre waves. Because of their non-ionising nature this kind of radiation is being considered to scan people. Finally, it has to be emphasised once again, that it is not possible to assign certain technologies to specific threats because of their complex nature and the capability of detection technology to indicate material properties that can be shared with numerous different substances. This fact even can be a serious reason for false alarms since e.g. nitroxid residues are characteristically for some, but not all explosives on one hand and certain medical drugs on the other hand.

2.2 An Example of Threat Detection

A new chemo sensor system for detecting certain explosives in the vapour phase has been studied recently at BAM that entails a combination of a highly selective Molecular Imprinted Polymer (MIP) with a high sensitivity transducer incorporating a fluorescent polymer in a tandem array. In the first stage the gaseous sample passes in a constant flow over the MIP where it is trapped by strong specific binding forces. In a second step the sample stream is replaced by heated nitrogen (140 °C) that causes desorption of the enriched sample which is consecutively measured in the transducer unit by determining the quenching of the fluorescence. As can be seen in Fig. **6**, the system is equipped with valves and gas flow controls designed to keep the transducer module always under nitrogen, even during the sampling phase. The intended application of the system is to detect trinitrotoluene (TNT), a substance with a rather low vapour pressure. However, some omnipresent impurities such as the dinitrotoluene (DNT) isomers are much more volatile so a MIP selective for one of those was chosen for this set-up.

Results of laboratory tests were reproducible and have been validated by parallel measurements with both, GC/MS and IMS devices. The robustness of the MIP to survive long periods of continuous operation up to a few years, the capability of miniaturisation, the potential of producing MIPs with selectivity for other substances and of manufacturing the components on a low cost base makes this concept particularly interesting for further developments. An array of various specific MIPs could make this kind of chemo sensors predestined for surveillance of trace detection at neuralgic sites of certain facility infrastructures such as air-conditioning systems.

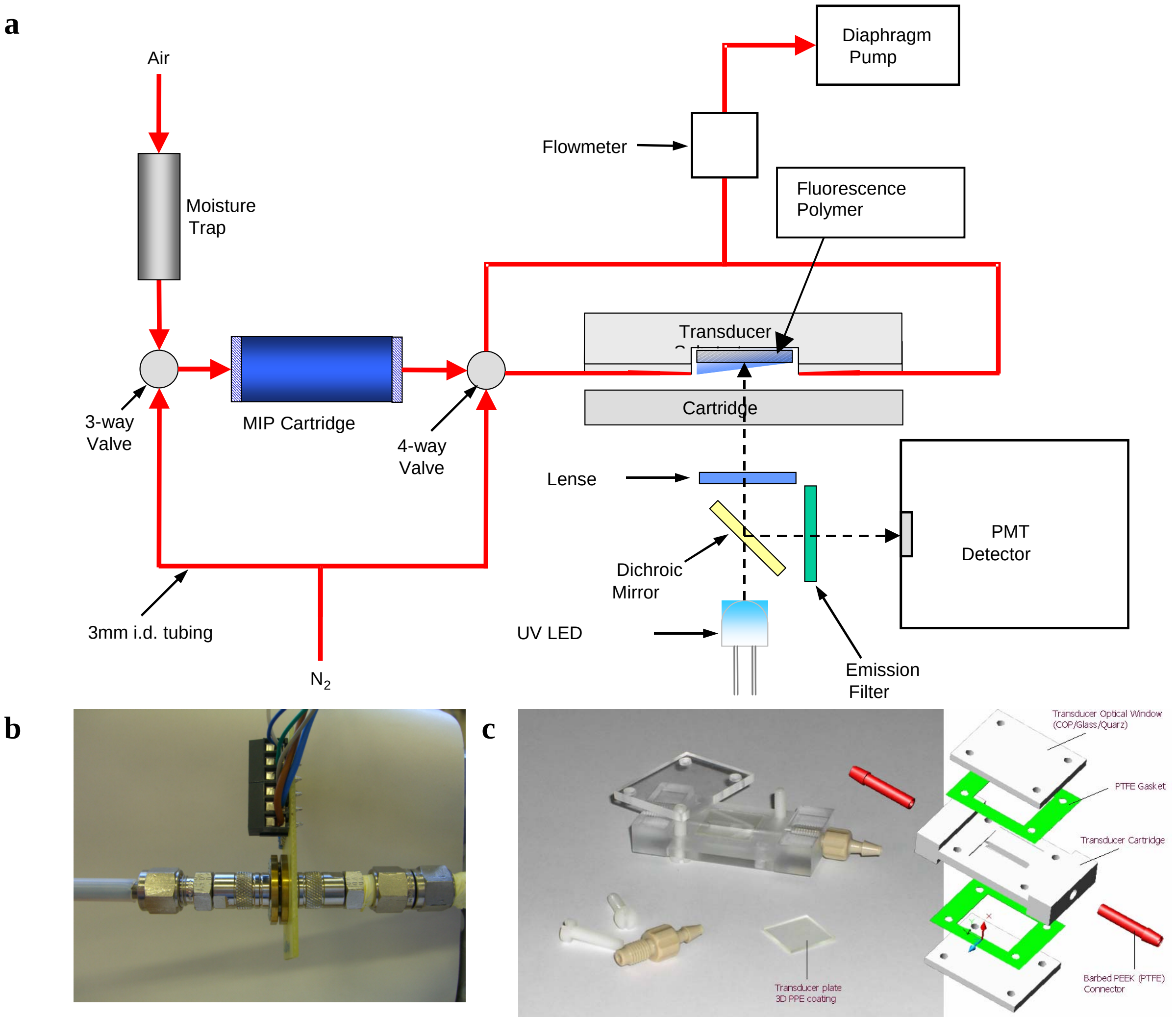
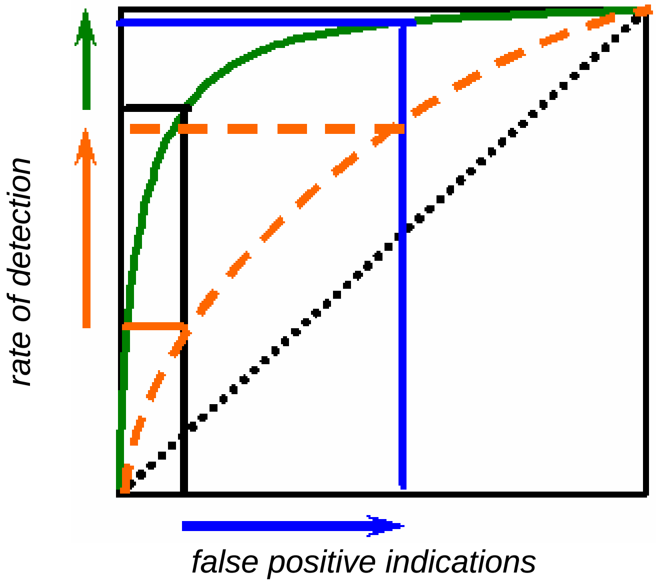


Fig. 6: TNT chemosensor device:
Functional diagram with molecular imprinted polymer (MIP) and transducer module as functional components, gas flow and optical unit (a), MIP cartridge (b) and transducer (c).

2.3 Reliability and Sensitivity/Selectivity of Detection Technologies as Countermeasures

Whenever a detection system displays a warning, further reactions are required depending on the intensity of the signal. In severe cases, this could have dramatic consequences ranging from activating extensive security and/or rescue systems to halting progress of events or even evacuating entire areas. It is easy to imagine that it could be a overwhelming nuisance revealing afterwards that the alarm has been a false one as a consequence of too high sensor sensitivity. On the other hand it is of course much more dangerous when the sensitivity is too low to detect the real existing threat. This problem has been principally tackled already in other fields: electronics, medical diagnostics and non-destructive testing, whenever yielding false indications as a result of increasing sensitivity. It has become common practice to show this graphically in so-called “receiver operating characteristic” (ROC) curves where the rate of detection is plotted against the number of false positive indications (Fig. **7**). The top of the diagram represents full detection of all truly existing indications while the diagonal (dotted line) has to be interpreted in a way that every correct detection has also one false indication, i.e., it represents the method of tossing a coin. The reliability of any practically useful system can be described by a curve between these two extremes. Since ideal conditions, i.e. complete detection without any false positive indication, cannot be reached in practical life, this kind of presentation provides a helpful tool for choosing operating settings with sufficient sensitivity for detection and an acceptable number of false positive indications. Moreover, it can also being used for comparing reliabilities of different systems where the best one is that one with the highest achievable sensitivity at a number of false indications not only acceptable but also as low as possible.



Increasing the sensitivity of any system (green: well, orange, poorly performing) results in a higher rate of detection (green and orange arrows on the left). However, at the same time, this makes also the number of false positive indication rising in both systems (blue arrow at the bottom). The position of the curve (green or orange) reflects the performance, and thus the reliability, of the system.

Fig. 7: Receiver Operating Characteristics (ROC) curves of a well (solid green line) and a poorly performing system (dashed orange line).

Since detector systems are designed and developed in scientific laboratories but finally operated in the fields by people not necessarily acquainted with the whole background of the technology it appears evident that the reliability found in laboratory conditions may be quite different from that resulting from practical use. So it is essential to assess functional reliability not only under ideal conditions but also in a realistic environment of intended applications and being operated by the security staffs currently in charge.

Conclusion

Numerous threats originating from explosives are presented by the daily news reports, sadly not only from the Near East but also from all over the world. Even worse, explosives are not the only source of danger; it has been shown that there is a variety of further means of attacks. So everyone might be threatened somewhere and somehow. As a consequence, appropriate countermeasures are of primary public interest. Detecting the source and specifics of a threat in time before it could cause harm is the first step in providing public security. However, the vast range of possible threats makes this task anything else but trivial. Therefore, a range of different detection technologies and traceability has to be considered for this purpose. Some of them are available, others need refinement and further developments are needed to improve both, selectivity and sensitivity.

A substantial number of analytical methods are already available nowadays for trace analysis employing sophisticated laboratory equipment. On the other hand, application in the fields requires a handling as easy as possible, fairly short response times including signal processing and a display of the result that is comprehensible for operators who are not necessarily scientists. Miniaturising of test devices with integrated electronics appears suitable to develop hand-held sensors for hazard detection.

References

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