GICHD

BASIC CHEMISTRY OF EXPLOSIVES AND HAZARDS OF HOME-MADE EXPLOSIVES AND CHEMICAL PRECURSORS

HANDBOOK

Cover image: Improvised explosive device main charges filled with unknown home-made explosive in Iraq (source: Fondation Suisse de Déminage FSD ©)

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We help national authorities, international and regional organisations, NGOs and commercial operators to develop and professionalise mine action and ammunition management. The GICHD supports around 40 affected states and territories every year.

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BASIC CHEMISTRY OF EXPLOSIVES AND HAZARDS OF HOME-MADE EXPLOSIVES AND CHEMICAL PRECURSORS

CONTENTS

1. INTRODUCTION

The widespread use of improvised explosive devices (IEDs) has been documented extensively by the mine action sector over the last decade[1]. Together with this trend is the use of home-made explosives (HMEs). Although not all IEDs include an HME component, the frequency of their use and the specific operational challenges related to HMEs and their chemical precursors, have highlighted the need to document good practice related to this lesser-known category of explosives.

The importance of addressing HMEs is clear. They pose a threat to human life and to the environment. There is also a significant risk that mine action (MA) personnel will encounter HMEs in affected countries, whether in improvised explosive devices (IEDs), in abandoned manufacturing or storage sites, or as stockpiles of precursor chemicals used in a variety of industries. The severity of the impact of HMEs coupled with a high likelihood of encountering them in certain settings, led to the decision to develop guidance that is focused on HMEs.

Given the risks involved for those in encountering HMEs and potentially interacting with them, the GICHD has developed Chapter 5 of the *Improvised Explosive Device Clearance Good Practice Guide* with the aim of improving the safety of mine action personnel as a first priority, but also ensuring that mine action programmes are dealing with this particular threat effectively to keep communities safe from their effects. This guidance therefore provides an important component of the mine action knowledge necessary to conduct IED search and disposal activities within the IED clearance process in relevant settings.

Our aims for this chapter have been addressed by presenting technical information on HMEs that will promote an increased understanding of these substances, including: the raw materials that compose HMEs; the ability to recognise their presence; the physical and chemical characteristics of HMEs; their potential to generate non-explosive hazards, such as toxicity; and, safety considerations for mine action personnel who are likely to encounter HMEs (such as Personal Protection Equipment (PPE)).

In order to strengthen and reinforce the knowledge about HMEs and their chemical precursors in the MA sector, this publication presents a wide variety of HMEs that can be encountered in operational contexts, and the chemical compositions used in their explosive train. Apart from discussing the more common HME groups (chlorates, perchlorates, nitrates and peroxides), substantial information has been provided on less commonly found mixtures, as well as on improvised pyrotechnics, improvised incendiary compositions and improvised primary explosives.

This chapter is neither a research publication nor a comprehensive technical manual; it rather aims to provide condensed content in an easy-to-read format. Visual aids and images of these chemical compositions are provided throughout the chapter to reinforce the learning process. The content has been chosen to provide practical knowledge to mine action practitioners, based on the most common HME threats they will encounter. Theoretical knowledge of the very basic chemistry of explosives and their chemical precursors provides the foundation of this document. Detailed scientific information, such as complex equations and formula have been avoided. Definitions and derivations have also been simplified to provide only the most essential information for end-users.

It is hoped that the technical knowledge presented in this chapter will be a useful operational resource that enables MA personnel to meet their primary needs for identifying and assessing chemical behaviour, as well as the risks related to non-explosive hazards. At the same time, reliable and accessible technical information also provides the foundations for high quality national standards, operational procedures, and policy documentation. We therefore hope that this chapter also proves useful in terms of developing the frameworks for MA programmes where IEDs are present.

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[1] The continuing high total recorded since 2014 is mostly the result of a large number of casualties recorded in countries facing intensive armed conflict and involving the largescale use of improvised mines (Landmine Monitor 2020, http://the-monitor.org/media/3168934/LM2020.pdf). While use by states has almost ended globally, significant numbers of anti-personnel mines, especially those of an improvised nature, continue to be laid by non-state armed groups, including in Afghanistan, Colombia, Nigeria, Yemen, several countries in the Sahel, and elsewhere. (Clearing the Mines 2021, Mineactionreview, https://www.mineactionreview.org/assets/downloads/3644_NPA_Clearing_the_Mines_2021.pdf)

1.1. SCOPE

The IED Clearance Good Practice Guide, Chapter 5 – *Basic chemistry of explosives and hazards of home-made explosives and chemical precursors* – is intended for use by MA staff trained in accordance with International Mine Action Standard (IMAS) 09.31 'Improvised Explosive Device Disposal' and IMAS 09.13 'Building Clearance'. It should be of use for humanitarian IED disposal operators but also for MA staff involved in the planning, execution, monitoring and follow-up of IED clearance operations.

This publication should also inform humanitarian aid workers, humanitarian first responders and explosive ordnance risk education practitioners, on the development of methodologies, approaches and tools that are specific to an environment where HMEs and their chemical precursors are present.

In this publication, terminology and definitions are presented in such a way as to be usable and accessible for the daily use of an MA organisation. The reader should be aware that the figures on chemical and physical properties used in this chapter are provided by laboratory trials where the experimental conditions for measurements exist. Under such circumstances, parameters such as fuel ratio or particle size would be known. In real contexts, such variables are unknown, including degradation of the composition through ageing, and for this reason the chemical and physical properties of an HME may differ considerably.

This chapter does not provide detailed guidance on the production process of HMEs, phlegmatisation[2] or disposal procedures.

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This publication's content has been put together from open-source information and has been assessed for accuracy and authenticity as far as possible. Because of their improvised nature, the parameters of HMEs will always vary. Regarding the properties of improvised explosives, statements in fixed numbers are hard to accomplish. Users should be aware of this limitation when utilising the information contained in this publication and should always remember that this is an advisory document only; it is not an authoritative directive.

This publication is not intended to replace IMAS-compliant training. It is not intended to 'convert' or 'expand' the remit of qualifications. The support of specially trained personnel may be required when encountering chemicals and HMEs.

This publication is not to be used to produce HMEs. It provides information required by the MA sector to increase safety when encountering HMEs or chemicals. Product information (for instance formulas, ingredient ratios) are not included on purpose.

This publication does not replace regulations defined by national standards and laws.

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[2] A phlegmatiser is a substance added to an explosive to enhance its safety in handling and carriage.

2. EXPLOSIVE MATTER

This section provides an overview of industrially manufactured and improvised explosives. It presents the basic concepts and emphasises hazard-related differences between industrially manufactured and home-made explosives (HMEs). An understanding of this section's content, combined with the basic knowledge of chemicals outlined in section 3 of this chapter, provides a solid basis for the information provided in this guide.

2.1. CONSIDERATIONS REGARDING EXPLOSIVES

2.1.1. CLASSIFICATION OF EXPLOSIVES ACCORDING TO THEIR COMPOSITION

An **explosive** is a substance or mixture of substances which, under external influences, is capable of rapidly releasing energy in the form of gases and heat.[3]

NOTE. An explosion is a sudden release of energy producing a blast effect with the possible projection of fragments. The term explosion encompasses fast combustion, deflagration and detonation.[4]

An explosion is caused within explosive matter if it is stimulated in a certain way. This stimulus can be induced by impact, friction, spark,[5] shock or heat. Furthermore, explosions can occur accidentally, for instance, when coal dust or petrol vapour mixes with air and is ignited by an external heat source.

Explosive (homogenous) compounds[6] are substances that contain an oxidiser and a fuel needed for an explosive reaction within their molecules. They are made of at least two precursor chemicals. During the manufacturing process, the chemical reaction of the raw materials leads to the creation of chemical bonds which combine to form a new homogeneous compound. This compound cannot be separated again by mechanical means (e.g. with a sieve or by dissolution in water). Common examples of industrially produced explosives which meet these requirements at their molecular level are trinitrotoluene (TNT) or Hexogen (RDX). Common examples of HMEs that are compounds are triacetone triperoxide (TATP) or hexamethylene triperoxide diamine (HMTD).

Image 2. Example of an explosive homogeneous compound: TNT (here used as filler for artillery shells) (source: GICHD ©)

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[3] International Ammunition Technical Guideline (IATG) 1.40, 3rd edition, March 2021.

[4] International Ammunition Technical Guideline (IATG) 1.40, 3rd edition, March 2021.

[5] Electric sparks are a very hot and fast-acting ignition source.

[6] Compounds are homogenous, meaning that the precursor chemicals are bonded on an atomic level. For instance, water H_2O is a homogenous compound of hydrogen H and oxygen O.

Mixtures of substances with explosive properties are made from at least two substances – an oxidiser and a fuel. Their individual components may be present in different aggregate states and / or consist of different substances. Both oxidiser and fuel are required for an explosive reaction. In a mixture, used precursor chemicals do not form a chemical compound, and can be separated again by mechanical means. Apart from some exceptions, standard oxidisers and fuels used in HME mixtures are non-explosive substances. Common commercial explosive mixtures are black powder or flash compositions,[7] common HME mixtures are ammonium nitrate and aluminium (ANAL), or urea nitrate and fuel oil.

Image 3. Black powder (source: Bundeswehr CBRN Defence Command ©)

NOTE. Explosive chemistry is dependent upon the transfer of one or more electrons from one atom to another. An atom losing an electron is said to be 'oxidised' and an atom gaining an electron is 'reduced'. An oxidiser is a substance or compound with an electron deficit and it is a source of oxygen. Within an explosive compound or an explosive mixture, the oxygen provided is required for an explosive reaction to take place. With this prerequisite, no atmospheric oxygen is required for an explosive to detonate (there are exceptions, such as dust explosions or fuel-air explosions for example). Typical solid oxidisers are nitrates, chlorates and perchlorates.

A fuel is a substance or compound that is electron rich and acts within an explosive as a chemical reducing agent. For HMEs, typical fuels contain carbon, hydrogen or nitrogen (or chemical compounds containing these elements) or metals such as aluminium, zinc or magnesium, which donate electrons during the oxidation-reduction reaction.

WARNING. Despite not being classified as explosives, precursor chemicals can pose several other hazards such as flammability, corrosivity or toxicity.

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[7] A flash composition is a mixture of an oxidiser and a (metallic) fuel which burns bright and quickly and, if confined, produces a loud noise.

2.1.2. CLASSIFICATION OF EXPLOSIVES ACCORDING TO THEIR APPLICATION

Beyond chemical aspects, industrially manufactured explosive matter is defined by its application as industrially used explosive or as military explosive. In addition, explosives can be divided into subcategories according to their application as primary explosives, secondary explosives, propellants or pyrotechnics. Further definitions and explanations will be provided in sub-section 3.1. of this chapter. Table 1 below provides an overview of the variety of explosive matter and its application.

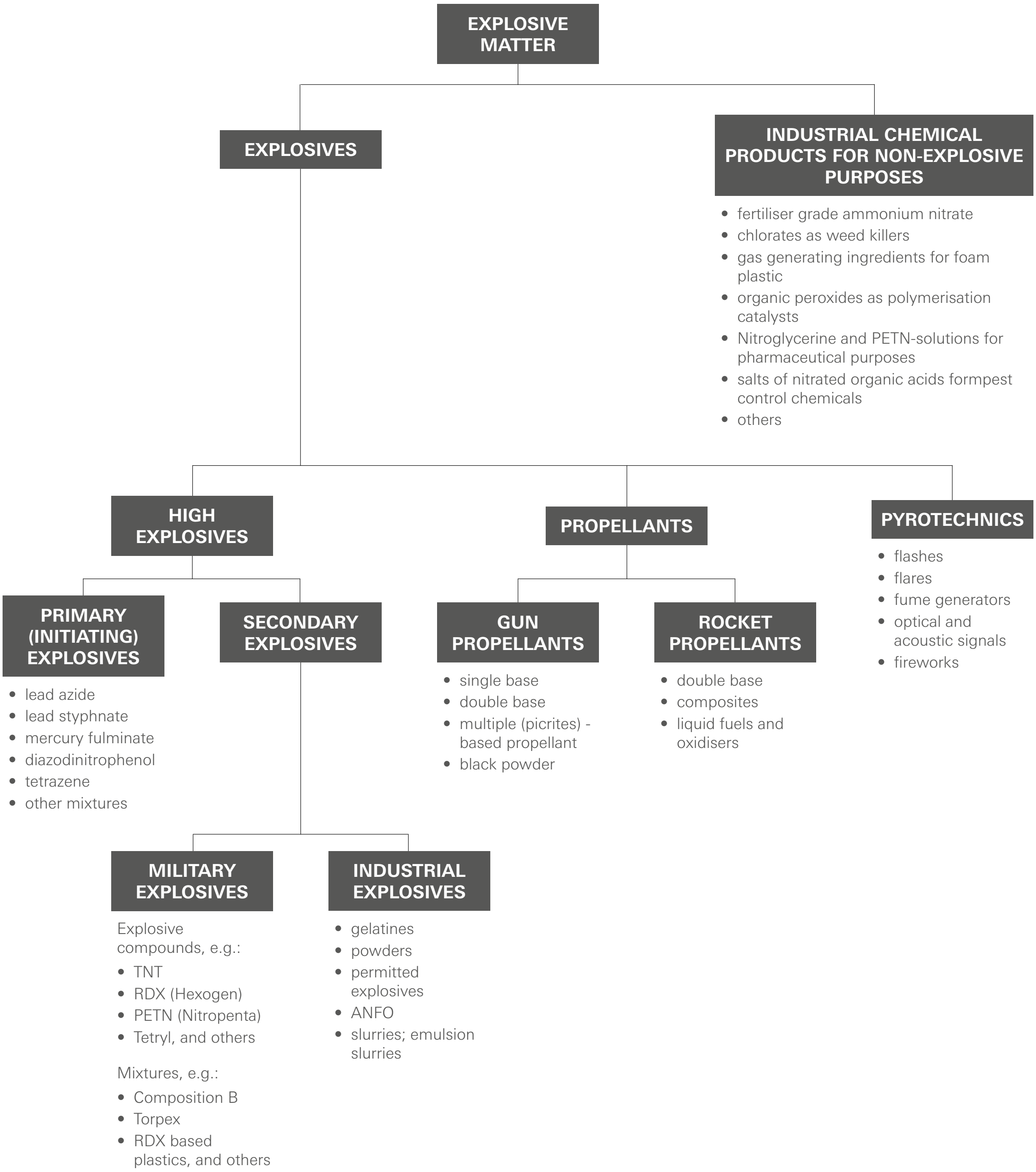

Table 1. Explosive matter and its application[8] (source: Wiley-VCH Verlag GmbH & Co. KGaA ©)

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[8] Rudolf Meyer, Josef Köhler and Axel Homburg, *Explosives*. Sixth Edition. (Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA, 2007), 134.

Industrially used explosives are designed and produced for commercial applications. An example is the gelatinous mining explosives used in quarries, or pyrotechnic mixtures used in airbags or fireworks. Explosive matter can be used for non-explosive purposes as well. Examples are the use of chlorates in pesticides, the use of ammonium nitrate in fertilisers or the use of nitroglycerine as a vasodilator[9] in medicine.

Military explosives are designed and produced for military purposes. Their performance is adapted to achieve a desired effect with regard to a target, and they may be deployed by an ordnance or a delivery system. Such performances can be:

- To create a high detonation velocity, used for driving metal liners to form shaped charges, for instance;
- To create a large volume of gas, used, for instance, for torpedo warheads, depth charges or sea mines; or
- To create a predictable, constant combustion rate combined with high heat resistance, used in solid rocket propellants, for instance.

Image 4. Example of a military explosive: remnants of a torpedo warhead filled with Torpex (RDX, TNT, aluminium powder and wax) (source: GICHD ©)

Both industrially used and military explosives are internationally and / or nationally standardised. Their manufacturing process follows established protocols and procedures. Their production is constantly monitored by qualified personnel and by using standardised methods. This ensures that their characteristic explosive effects will remain constant whatever their use. In general, this applies to all of their performance throughout their service life.

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[9] Vasodilators are medications that open (dilate) blood vessels.

2.2. CONSIDERATIONS REGARDING HMEs

2.2.1. BASICS OF HME

HME is predominantly a mixture of commercially available fuels and oxidisers; some homogeneous compositions are encountered as well. Usually, HME is in a solid or liquid state. In some instances, it can be transported as a two-phase system, enabling quick mixing prior to use. As with most military and industrially used explosives, the oxygen necessary for a detonation of HME is found within the mixture or the composition itself. This means that HMEs are largely self-sufficient in oxygen. This is a hugely important distinction from other flammable substances which rely on atmospherically available oxygen. Since the production of an HME does not follow the same stringent manufacturing process as an industrially used or military explosive, it is impossible to assure its performance, reliability and safety.

NOTE. IMAS 04.10 'Glossary of mine action terms, definitions and abbreviations' defines HME as 'a combination of commercially available ingredients combined to create an explosive substance.'

The UNMAS Improvised Explosive Device Lexicon defines HME as 'non-standard explosive mixtures/compounds which have been formulated/synthesized from available ingredients. Most often utilized in the absence of commercial/military explosives.'

2.2.2. HME-RELATED HAZARDS

In the press, as in the news, the term HME is generally used for reports concerning the discovery of main charges or improvised detonators containing HME used in improvised explosive devices (IEDs).

Image 5. Example of different main charges filled with HME
(source: Fondation Suisse de Déminage FSD ©)

However, focusing on this usage limits the perception of HME-related hazards. HMEs are not only used in primary explosives or secondary explosives but in propellants and incendiary or pyrotechnic compositions as well. Apart from their use in improvised explosive devices (IEDs), HMEs and explosive chemical precursors have also been found in:

- Abandoned storage facilities;
- Abandoned manufacturing facilities;
- Transportation assets; and
- HME manufacturing waste.

2.2.3. FACTORS AFFECTING PRODUCTION, SAFETY, RELIABILITY AND PERFORMANCE OF HMEs

In military or commercial explosive design and manufacture, the choice of ingredients basically depends on the effectiveness that a user requires throughout the service life of a product. This effectiveness is very much governed by a combination and balance of **safety**, **reliability** (ability to function as intended) and **performance**. These three attributes are explained below. If safety and reliability cannot be guaranteed or the performance is suboptimal, then sensible trade-offs are applied. A variety of explosives are ruled out as useful for military or commercial explosive applications because the trade-offs are unacceptable, for instance due to a lack of stability of an explosive, or because it is considered unsafe due to the high sensitivity of an explosive to external impulses. Some of the explosives ruled-out by military and commercial users were / are encountered as HMEs.

NOTE. TATP is an example of an explosive excluded from industrial use because of its tendency for sublimation and its high friction sensitivity (compared to other (primary) explosives). A common synonym used for TATP by some (illegal) manufactures is Mother of Satan, referring to its sensitivity and (devastating) instability. The mixture of potassium chlorate and paraffin wax, known as 'cheddite' in the early 20th century, is an example of a military explosive overtaken by more powerful compositions in the development of artillery shells.

Where military ordnance and explosives are accessible, their use is always preferred in the design and manufacture of IEDs because their safety, reliability and performance are guaranteed. There are no requirements for chemical processing, no requirements for special knowledge or the need for equipment required in the manufacturing of HMEs. However, the 21st century has witnessed improvements in stockpile security, humanitarian demining initiatives and the disruption of supply chains by the international community, which has led to the increased use of HMEs. There is such a variety of fuels and oxidisers to choose from, and given that many precursors are used for legitimate purposes, they may not be classed as explosive or incendiary, making international policing extremely difficult. But, when physically or chemically combined, processed or synthesised with other precursors, they can wreak havoc.

HME design, manufacture and use is often fraught with unsafe and sometimes complex chemical procedures. Many explosive products that are used as HMEs have been discounted in military or commercial applications because their performance is not underpinned by safety and reliability. Making effective HMEs is not, therefore, a simple or reliable choice. Some of the reasons for this:

- Strong acids and bases, already toxic and corrosive chemicals themselves, may be required to manufacture, to synthesise or to act as catalysts or reactants;
- Intermediates in a production process can be difficult to control without specific and reliable equipment, this can lead to violent reactions, to self-ignition or even to self-initiation;
- The presence of chemical impurities in manufacturing equipment can make the explosive product more sensitive;

- The availability of the precursor chemicals themselves: cheaper products may have lower purity (for instance leading to the requirement to process larger amounts or the need to add an additional processing step, as lower purity may influence reliability and performance of the product), or the fuel and oxidiser may not be present in the amounts necessary to create an optimum mixture; and

- The physical properties of the precursor chemicals themselves – for instance, particle size, purity, variation in crystal habit can each lead to highly unstable mixtures (at point of manufacture or over time) which can be inadvertently initiated by heat, friction, static electricity, shock or impact.

The consequences of assuming that an improvised explosive has the same physical characteristics as its standardised, industrially produced counterpart could therefore be fatal for mine action (MA) staff or first responders. For example, black powder is a dense mixture of potassium nitrate oxidiser (75% by weight), charcoal fuel (15%) and sulphur fuel (10%). These quantities are published in open-source material and commonly available. Deviations in the quantities of the starting materials, particle size, purity, mixing time, moisture or type of wood used to prepare the charcoal, may all influence the safety, reliability and performance of black powder. These deviations are hardly visible but, in the worst case, may pose additional risks such as an increased sensitivity to friction and heat. The aim of this example is to demonstrate how hard it can be to assess safety, reliability and performance of HMEs, simply based on a comparable commercial product. Apart from the explosive risk, serious health hazards must be taken into consideration when encountering HMEs and their precursor chemicals.

NOTE. The resources, capabilities and knowledge of an HME manufacturer influence the quality and physical characteristics of HME. Consequently, HME can differ greatly from its commercially produced counterpart.

Image 6. Main charges filled with HME of unknown quality and sensitivity posing explosive and non-explosive hazards (source: FSD ©)

The classification of explosive matter according to its application is illustrated in Table 1 in sub-section 2.1.2 above. This classification is used throughout this publication. Where feasible, the system used to classify HMEs in this publication is based on their oxidisers, as these are a significant variable affecting an HME's physical characteristics.

2.3. COMPARATIVE CONSIDERATIONS BETWEEN INDUSTRIALLY MANUFACTURED EXPLOSIVES AND HMEs

Both industrially manufactured explosives and HMEs are produced to be deployed as explosive substances.

For HMEs, two methods can be observed:

- Copying the methods of production for a commercial explosive; and
- Producing an improvised explosive from available fuel and an oxidiser.

The following three images of TNT demonstrate the possible appearance of industrially produced TNT compared to that of home-made TNT.

Image 7. Industrially produced TNT (source: Bundeswehr CBRN Defence Command ©)

Image 8. Industrially produced TNT (source: Bundeswehr CBRN Defence Command ©)

Image 9. Home-made TNT (source: Bundeswehr CBRN Defence Command ©)

2.3.1. INDUSTRIAL MANUFACTURING

Industrially manufactured explosives, regardless of their application in the commercial or military sectors, are produced by experienced chemists and engineers. The products, as well as their synthesis, are standardised. During manufacture the following features are consistent:

- Ratio of ingredients;
- Degree of mixing and purity and volume fraction of the raw materials;
- Density of the explosive produced;
- Particle size;
- Particle shape (or crystal habit); and
- Addition of additives, to stabilise or phlegmatise (desensitise) the explosives, for instance.

Automated production is carried out under strict industrial hygiene conditions and contamination with other substances (leading to high-risk effects of ageing, for instance) is highly unlikely. Such measures are taken for safety and economic reasons, and to maintain the quality and performance of the product during its lifespan.

2.3.2. IMPROVISED MANUFACTURING

The majority of HMEs are locally manufactured by groups or individuals who, in general, are poorly trained to carry out this task compared to the training standards used by industry. They possess the knowledge of 'how' (the manufacturing process itself) and 'why' (such as the necessity for the order of different manufacturing steps) from the internet or from organisational training, manuals and guides ('cookbooks') but do not necessarily have the awareness (the 'what') of potential dangers associated with the production process or final product. The basic knowledge of risk mitigation, of production measures and their application, is often limited compared to industrial standards, drawing attention to the fact that these compositions and mixtures are 'improvised' and therefore unpredictable. However, there are exceptions where highly trained individuals have produced sophisticated improvised explosives, adapting measures of risk mitigation. These exceptions should not be considered as a standard when interacting with HMEs.

The choice of a manufactured HME is mainly determined by the resources available within a supply chain, organisational knowledge and capability, and an improvised explosive's specific purpose (whether an explosive, incendiary or propellant composition / mixture is required).

Image 10. Explosive chemical precursors found in field conditions (source: GICHD ©)

Manufacturers may be forced to improvise to create the required precursors when (laboratory-grade) chemicals are not available. In addition to an already improvised recipe, lack of resources may force them to synthesise precursors or use substitutes containing a concentration of the required chemical substance or compound. For instance, if an oxidiser such as ammonium nitrate is not available then barium nitrate or potassium nitrate could be used. Besides additives, these explosive precursor substitutes may contain impurities that do not affect the intended commercial use of the chosen substitute but which could have dire consequences in an HME. This systematic approach of improvisation by manufacturers is applied when making an improvised explosive, as well as when harvesting a substance from an available mixture, such as harvesting ammonium nitrate from calcium ammonium nitrate fertilisers.

Image 11. A bag of potassium nitrate fertiliser. This fertiliser can be used to harvest potassium chlorate (source: Conflict Armament Research CAR ©)

Improvised explosives can be contaminated with a wide variety of chemical substances, which may act as sensitisers. These impurities, whether they be chemicals such as acids or low melting point solids, such as sulphur, can lead to instability. They can increase the sensitivity of HMEs to friction, burning or detonation, or create unintended side effects such as the production of heat or the formation of dangerous by-products. For instance, if potassium chlorate is contaminated with sulphur or ammonium nitrate, then the sensitivity of the mixture to friction and heat increases considerably. Such contamination can lead to spontaneous explosions of these mixtures during handling and transportation, even at room temperature.

⚠ **WARNING. Friction creates heat within a composition or a mixture by introducing pressure between crystals and compressing trapped air within voids. These areas of localised heat within explosives can lead to unintended decomposition.**[10]

⚠ **NOTE. Performance and stability of HMEs can differ greatly from the results of a laboratory analysis. Limited resources and lack of knowledge on the part of the HME manufacturer will therefore exacerbate safety risks for MA staff when dealing with improvised explosives. When encountering HMEs, MA staff should always consider that the improvised explosive has not been produced to an industrial standard and should therefore be treated with particular caution.**

Industrially manufactured explosives must fulfil certain minimum requirements on performance, sensitivity, stability, thermal behaviour, behaviour in storage, water resistance and consistency, prior to acceptance for use. These minimum requirements may differ in accordance with the norms of a customer (e.g. the military) or a state's regulations.

PERFORMANCE	The physical characterisation of an explosive corresponds to its intended use, for instance, low detonation velocity for mining explosives.
SENSITIVITY	An explosive must be safe to handle. It should be blasting cap (detonator) sensitive or sensitive to flame under the required conditions of its use. Military explosives are required to be as insensitive as possible because of the rigours of service use.
STABILITY AND BEHAVIOUR IN STORAGE	An explosive must remain chemically stable over a certain amount of time, as defined by its purpose and use. For military explosives, this stability span can be up to 10 years or more. Effects of ageing limiting the use of an explosive should not occur within this period. An explosive must not react adversely with the environment, so primary explosive compositions must not react with the metal casing of their blasting cap, for instance, and secondary explosives must not react with their munitions casing.
WATER RESISTANCE	When cartridged, industrial explosives should withstand the effect of two hours in stagnant water. Military explosives should be completely waterproof and withstand saltwater corrosion.
CONSISTENCY	Industrially used explosives should be formable, military explosives should be castable or pressable.
THERMAL BEHAVIOUR	Industrially used explosives are expected to be fully functional in the range of -25° / +60°, and military ones between -40° / +60°.

Table 2. List of requirements for industrially used and military explosives

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[10] A more detailed explanation can be found in sub-section 3.3.4. *Sensitivity and sensitiveness*.

WARNING. The behaviour of stored HMEs can be influenced by their reactivity. For example, using a copper or brass container with ammonium nitrate[11] or lead azide increases their sensitivity to detonation.

Safety considerations concerning a product and its service lifespan as described, or required for industrially produced explosives, are not a determining factor for HMEs. Improvised explosives are often produced out of acute necessity and are not usually required to remain functional or stable for extended periods of time. The safety considerations for HMEs are therefore limited by the producer's acceptance of risk, such as premature explosion.

HMEs usually suffer more from the effects of ageing in a shorter period than industrially produced explosives. The handling safety and sensitivity of some HMEs is often dependent on humidity, temperature and the degree of contamination present during manufacture. For example, some HMEs requiring the use of nitric acid or sulphuric acid in their production can deflagrate or detonate over time, if excess acid remains in the mixture.

Image 12. VS-500 exhibiting expansion of the HME due to moisture as an effect of ageing (source: FSD ©)

When handling, the safety of improvised explosives should be considered to be lower than that of industrially manufactured explosives. HMEs' sensitivity often exceeds that of industrially manufactured types. In addition to their explosive hazards, both types can pose a serious, sometimes lethal, threat to health due to their toxicity.

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[11] More information can be found in sub-section 3.2. *Explosive reactions*.

EXAMPLE: COMPARISON OF PRODUCTION PROCEDURES

Even when explosives seem identical, the available resources for manufacturing and the capabilities of the maker to extract and process the raw materials have a significant impact on the final product.

Ammonium nitrate–fuel oil (ANFO) is a widely available commercial explosive used primarily in mining and quarrying operations. Home-made ANFO is used as an improvised explosive in IEDs worldwide.

Commercially explosive ANFO is made from technical-grade ammonium nitrate (density: 0.7–0.9 g/cm^3; non-homogenous prills[12] with a 1 mm diameter) and an organic fuel such as kerosene or diesel. Up to a certain grade, the AN-fuel oil ratio is used to steer the detonation velocity and therefore the explosive performance. Sensitisers can be added to improve the initiation process. Phlegmatisers can also be used to downgrade the detonation velocity.

For HMEs, harvesting fertiliser-grade ammonium nitrate (density: 0.9–0.97 g/cm^3; homogeneous prills with a 2 mm diameter) from nitrogen fertilisers containing ammonium nitrate, is a common approach to sourcing this raw material. Fertiliser-grade ammonium nitrate has a relatively low porosity.[13] These nitrogen fertilisers contain further chemical compounds such as phosphorus, sulphur, potash, urea and cloaking agents to prevent caking.

Regardless of how an ammonium nitrate fertiliser is advertised, HME manufacturers will be able to harvest explosive-grade ammonium nitrate crystal from it when using the proper procedure. A fertiliser's ammonium nitrate content will steer the amount of ammonium nitrate crystals that can be extracted. It is generally limited to below a certain percentage to make HME manufacturing without further processing more difficult. Unlike technical-grade ammonium nitrate, (extracted) fertiliser-grade ammonium nitrate will contain impurities and contamination due to the original manufacturing process.

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[12] A prill is a pellet or solid globule of a substance formed by the congealing of a liquid during an industrial process.

[13] Porosity represents the ratio of void volume to total volume of a substance or mixture of substances.

	TECHNICAL GRADE (TGAN)	HIGH DENSITY / FERTILISER GRADE (HDAN/FGAN)
Description	Prills Coarse and porous Matt white Diameter ~1 mm non-homogenous  	Prills Slick Glossy white Diameter ~2 mm homogenous 
Density	0.7 – 0.9 g/cm^3	0.9 – 0.97 g/cm^3
Remarks	POSSIBLY prills are ground when ready for use HIGHLY LIKELY mixed with a fuel when ready for use ➔ colour changes according to the fuel used AN + aluminium 	HIGHLY LIKELY prills are ground when ready for use HIGHLY LIKELY mixed with a fuel when ready for use ➔ colour changes according to the fuel used AN + fuel oil 

Table 3. Comparison of different grades of ammonium nitrate (source: UNMAS ©)

3. PHYSICAL AND CHEMICAL BASICS REGARDING CHARACTERISTICS OF EXPLOSIVES

This section provides an overview and explanation of key technical terms and definitions used to describe energetic materials and explosive substances. The objective is to create a common understanding of HMEs and industrially manufactured explosives among mine action (MA) staff, first responders, and aid workers, in order to support risk management and operational planning. This section also addresses physical characteristics in relation to safety and sensitivity. Hereafter, the detail and level of complexity of the terminology used is adapted to fulfil the requirements of this guide and may be simpler than that used in scientific publications.

⚠ **NOTE. The term HME is equated with (or used as a synonym for) primary or secondary explosive. This approach is incorrect since improvised explosive matter is also used in pyrotechnic or propellant applications.**

3.1. CLASSIFICATION OF EXPLOSIVES

This sub-section provides a commonly agreed classification of explosives. This knowledge may be of use to identify explosives and their use, to differentiate between hazards or to improve reporting.

Whilst there are several ways to classify explosive substances, a common method is to categorise them by their performance and use (see sub-section 2.1.2, Table 1).

Explosives are categorised as:

- High explosives, that can be subdivided into:
    - Primary explosives;
    - Secondary explosives;
    - Tertiary explosives; and
    - Insensitive explosives.[14]
- Low explosives or propellants; and
- Pyrotechnics.

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[14] Insensitive explosives are particularly resistant to external stimuli such as mechanical shock or heat. The chance of them detonating unintentionally is very low.

3.1.1. HIGH EXPLOSIVES

In the design of military and industrial explosives, the main issues considered are:

- Whether burning or detonation is required for the explosives to do the necessary work; and
- How easily they are initiated to do this work.

The term '**high explosive**' is used if an explosive detonates instantaneously. The reaction front moves through an explosive with a velocity equal to or higher than the explosive's speed of sound. Large amounts of energy in the form of heat and gas are liberated in microseconds because there is a requirement to 'do work' on the surroundings such as shattering, damaging, bursting, penetrating, lifting / heaving, creating shock waves / air blast / underwater pulses / to project fragmentation over a wide area. The reaction velocity is of the magnitude km/s.

3.1.1.1. PRIMARY EXPLOSIVES

Explosives which are readily initiated by a small stimulus are known as primary explosives (or initiating explosives). They can deflagrate or detonate whether confined or unconfined and the transition from combustion to detonation is extremely rapid. Primary explosives are most often used to initiate reactions whereby their chemistry produces a shock wave (or burn rate) of sufficient magnitude to deflagrate / detonate a less sensitive explosive. Ignition for the majority of primary explosives is via inter-crystalline friction, which leads to the generation of hotspots (spots in an explosive where adiabatic compression of small, occluded gas bubbles generates up to 400°C-500°C heat; these spots exist for 10^{-5} seconds) necessary to commence the explosion process.[15] In general, primary explosives are much more sensitive to friction, heat, sparks and shock than secondary explosives. This characteristic makes them essential to the function of a detonator or blasting cap. Examples of primary explosives are lead styphnate, mercury fulminate, lead azide, dinitrobenzenediazoxide (DDNP), tetrazene, HMTD and TATP, all of which have been used as detonators in HME compositions. However, some primary HME compositions such as TATP and HMTD have been used as both primary and secondary explosives, given their explosive performance.

NOTE. For explosives, the term 'ignition' refers to the commencement of combustion, the term 'initiation' refers to the commencement of a deflagration or detonation reaction.

Image 13. Improvised electric blasting caps containing a primary explosive (source: FSD ©)

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[15] John E. Field, "Hot Spot Ignition Mechanisms for Explosives," *Acc. Chem. Res.* Issue 1 (1 November 1992): 489–496.

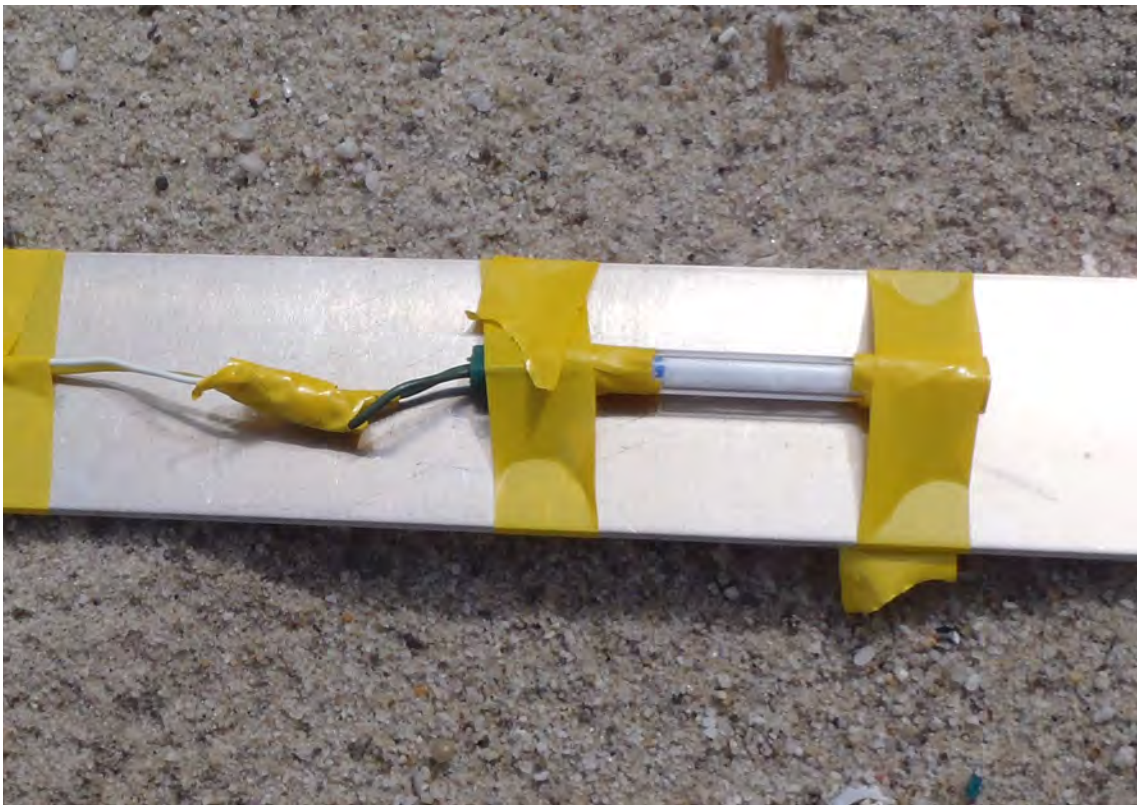

Image 14. An improvised detonator (filler: TATP) on an aluminium witness plate (source: Brimstone Consultancy Limited BCL ©)

Image 15. The effects of an improvised detonator (filler: TATP) on an aluminium witness plate (source: BCL ©)

3.1.1.2. SECONDARY AND TERTIARY EXPLOSIVES

Explosives which require a large stimulus to detonate (that being the impact of a shock wave to bring about detonation) are known as secondary explosives. The requirement of a large stimulus means that secondary explosives cannot be reliably detonated on their own without an external explosive force. Generally, a primary explosive is used to provide the shock to cause detonation. Initiation of secondary explosives is primarily through the compression of small gas spaces between crystals. Secondary explosives are relatively insensitive to heat, kinetic shock, electrostatic discharge and friction, making them safe enough in routine handling, moulding and transport. Some secondary explosives, such as pentaerythritol tetranitrate (PETN), are slightly more sensitive and have a very high detonation velocity – larger than 8400 m/s. Such explosives can be used as booster charges for tertiary explosives. Examples of secondary explosives are octogen (HMX), RDX, TNT and tetryl. Important characteristics defining the performance of secondary explosives are detonation velocity and strength (explosive power). Their power (the ability to do work on the surroundings) is determined by the heat of the explosion itself (the amount of heat available to expand the gaseous products) and the amount of gas produced per unit of volume of the explosive.

⚠ **NOTE. Whilst secondary explosives used in military or commercial applications are less sensitive than their primary counterparts and are, in general, safe to handle, this does not mean that HMEs with the (assumed) properties of a secondary explosive are automatically safe to handle or less affected by external influences. The presence of impurities, effects of ageing and the mixing of primary and secondary HME compositions within the same main explosive charge makes their performance unpredictable.**

Image 16. PETN, a secondary explosive (source: Bundeswehr CBRN Defence Command ©)

Depending on their chemical characteristics or processing method, some secondary explosives are very insensitive and cannot be initiated by a primary explosive using a detonator alone. In this case, a booster made of an explosive that can be initiated by a primary explosive is used to provide enough shock to initiate this secondary explosive. The combination of a detonator with a primary explosive, a booster and a main charge, both with a secondary explosive, is called the detonating or explosive train.

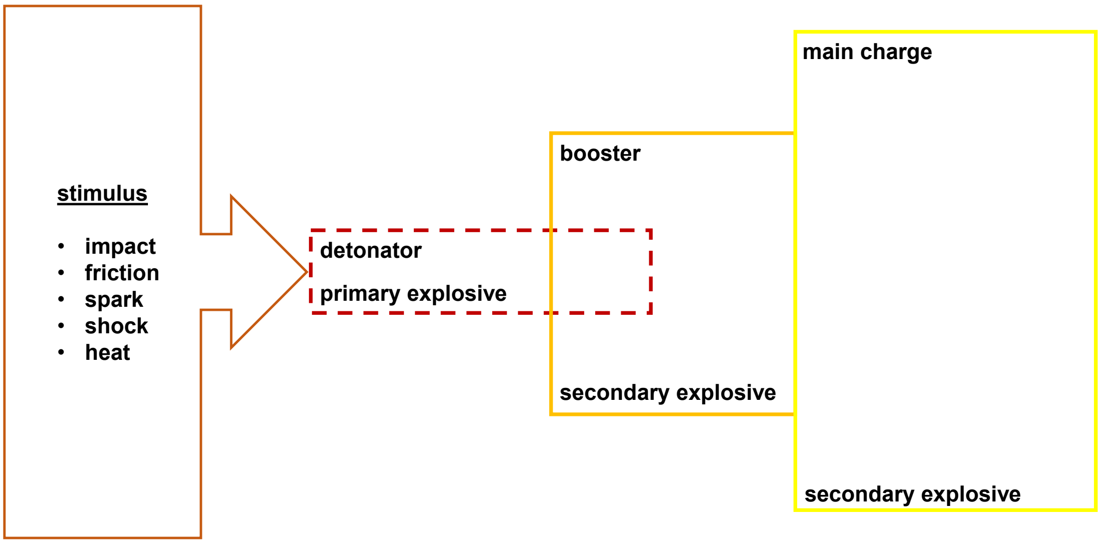

Figure 1. Basic schema of an explosive train. A primary explosive in a detonator is initiated by an external stimulus. As a next step, its detonation initiates a secondary explosive in a booster. The shock wave created by the booster's detonation stimulates a secondary explosive of a main charge, and the main charge detonates. (source: GICHD ©)

Explosives requiring a booster are sometimes referred to as tertiary explosives. Ammonium nitrate mixtures, HMX, nitrotriazolone, guanidine nitrate, nitroguanidine and some hydrogen peroxide-based explosives are commonly considered as tertiary explosives.

Image 17. Boosters for HME main charges made from improvised detonating cord (source: FSD ©)

⚠ **WARNING. For HMEs that require a primary explosive to be initiated, it should not be assumed that they have a comparable level of (in)sensitivity to military or commercial secondary or tertiary explosives.**

⚠ NOTE. An explosive train may incorporate a mix of commercial, military and home-made explosives, depending upon supply chain availability and the sensitivity to detonation. For example, ammonium nitrate-based HMEs are insensitive to shock alone and require a booster of more powerful commercial / military explosive (such as tetryl or PETN) to achieve detonation. An illustration of this was in an improvised sea mine used in Yemen, in which the 20.3 kg ammonium nitrate–aluminium main charge was initiated by a 0.7 kg RDX booster and commercial detonator.[16] A critical diameter, which exceeds those of military explosives, is also required to propagate detonation, which is one of the primary reasons why ammonium nitrate-based HMEs are often greater than 20 kg in mass; a useful observation for MA specialists since it separates large devices from those which are ergonomically man-portable (< 20 kg).

3.1.2. LOW EXPLOSIVES OR PROPELLANTS

The term '**low explosive**' is used for explosives (propellants) that decompose by deflagration when unconfined. The reaction front moves through the explosive with a velocity slower than the explosive's speed of sound. Propellants are designed to burn quite rapidly (in the order of milliseconds) under confinement to maximise the volume of hot gases produced. This is normally required to provide thrust, thereby projecting a high explosive or other such material to a specific point where its work is required. The reaction velocity is of the magnitude m/s. Ideally, a propellant's combustion is rapid and predictable. This chemical reaction will take place with the following characteristics:

- Without additional atmospheric oxygen;
- Exothermically; and
- Involving the creation of large volumes of hot gases as the propelling medium.

Propellants are produced in powder, pellet, solid piece or liquid forms. Examples of propellants are nitroguanidine and nitroglycerine compositions for tube fired ammunition or hydrazine, a liquid propellant used in missiles.

⚠ **WARNING. In general, propellants are designed to rapidly burn or combust. Contamination with other chemical agents, confinement or sudden large-scale mixing of the fuel and the oxidiser of a hypergolic liquid propellant (as used in some rocket motors) can lead to a propellant's explosive decomposition.**

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[16] Letter dated 26 January 2018 from the Panel of Experts on Yemen mandated by Security Council resolution 2342 (2017) addressed to the President of the Security Council. A. Himmiche, F.R. Carvajal, D.R. Gunaratne, G. Johnsen, & A. Wilkinson, p. 170, Table 41.1.

Image 18. Example of the burning behaviour of solid propellants when unconfined (source: GICHD ©)

Image 19. Propellant made of nitrocellulose (source: Bundeswehr CBRN Defence Command ©)

Image 20. Another example of propellant made of nitrocellulose. Drilling holes increases the surface of the prill and, therefore, the burning action. (source: Bundeswehr CBRN Defence Command ©)

3.1.3. PYROTECHNICS

Pyrotechnics are specific mixtures of fuels and oxidisers designed to burn, not deflagrate or detonate. Their reaction velocity is much lower than that of propellant explosives and in the region of mm/s. The heat generated is used to produce a combination of light and colour (flares, fireworks), smoke (obscurants), heat (thermite and thermate), noise (flash bangs and battlefield simulators), working gases (such as in car airbags) and delay compositions (hand grenade fuses, time fuses, safety fuses). Pyrotechnics react exothermically with chemical reactions that are (mostly) non-explosive, self-sustaining and self-contained.

Pyrotechnics are energetic compounds and / or mixtures with different sensitivities by design.

- Pyrotechnics may show detonation-like effects under certain conditions, for instance, if confined.
- Most pyrotechnics are mixtures of a fuel and an oxidiser. Oxidisers are the relevant substance for the strength achievable by a mixed HME.
- Groups of pyrotechnics suffer from ageing effects and have a very limited storage life.

3.2. EXPLOSIVE REACTIONS

This sub-section provides a short summary of explosive reactions. This knowledge should be of use to reinforce an understanding of energetic reactions and to support risk and hazard assessments.

The main energetic reactions to consider for explosives are:

- Combustion;
- Deflagration; and
- Detonation.

Deflagration and detonation are differentiated from usual combustion by their power output, propagation velocity (some mm/s for combustion, several hundred m/s for deflagration and several thousand m/s for detonation) and the oxygen source that they use. Each of these reactions is determined by the chemical characteristics of the energetic material, including the required ignition or initiation energy, the substance’s energy density, as well as confinement and the effects of ageing and other deteriorating processes.

Combusting or deflagrating substances decompose through a thermal mechanism that takes place on the surface of the material, whilst detonating substances decompose extremely quickly causing a shock wave. This is summarised in the following figure and tables.

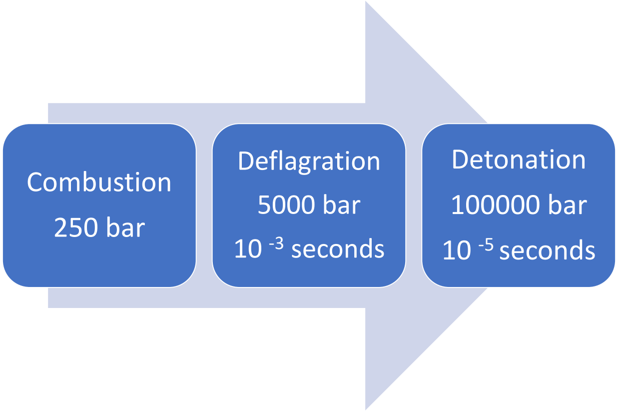

Figure 2. Energetic reactions (source: GICHD ©)

REACTION TYPE	REACTION RATE	POWER OUTPUT AND PRESSURE	OXYGEN SOURCE	EXAMPLE
Combustion	Slow (mm/s)	100 W/cm^3 250 bar	Atmosphere	Burning wood
Deflagration	Subsonic (+100 m/s)	100 W/cm^3 5000 bar	Within compound	Confined black powder
Detonation	Supersonic	1000 W/cm^3 100000 bar	Within compound	TNT

Table 4. Overview of the characteristics of combustion, deflagration and detonation

3.2.1. COMBUSTION

Combustion is a chemical reaction that takes place between an ignited substance and external (e.g. atmospheric) oxygen. The reaction takes place on the surface of the material. Combustion happens within seconds; it is a slow chemical reaction.

Combustion generates heat and smoke and can create a pressure of up to 250 bar.

Energetic substances which decompose via combustion are used in applications such as rocket motors and safety fuses.

3.2.2. DEFLAGRATION

Deflagration takes place when an unconfined substance ignites suddenly when exposed to flame, spark, shock, friction or high temperature.

The substances react faster and are more violent than combustible substances. However, the reaction still takes place on or just above the surface of the material, which recedes layer by layer.

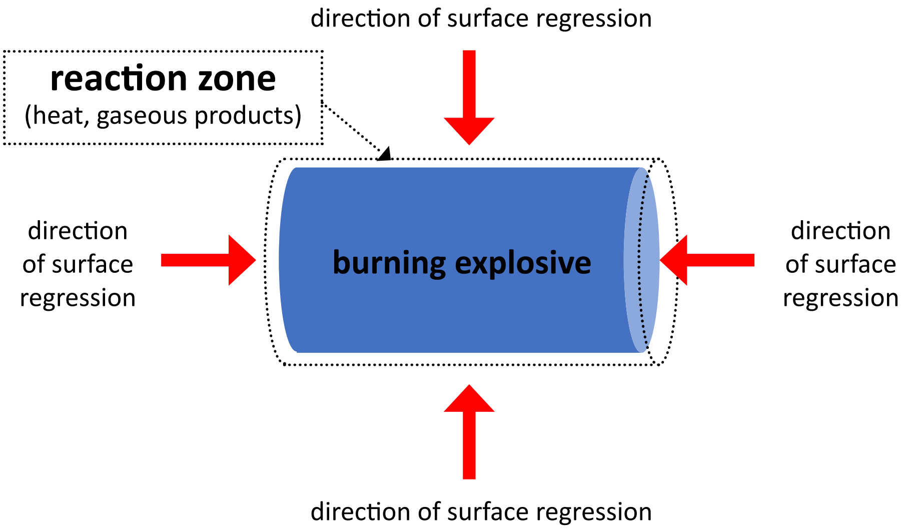

Figure 3. Schema of a burning / deflagrating explosive (source: BCL ©)

Deflagration takes place within milliseconds (10^{-3} sec.); it is considered a fast-chemical reaction, but its speed is still subsonic.

Deflagration generates heat, smoke and pressure of up to 5000 bar.

The effect of substances which decompose via deflagration is used, for instance, as the propellant for small arms ammunition in firearms. The term deflagration is often used to describe a violent burning of an explosive which has failed to detonate.

3.2.3. DETONATION

Detonation takes place when an initiated substance decomposes through a shock wave. It is defined as an extremely fast explosive decomposition, in which an exothermic reaction wave maintains a shock front in the explosive material. The velocity of this shock front can be in the region of 1800–10000 m/s, depending on the explosive. Unlike a deflagration, the rate at which the material decomposes is not governed by the rate of heat transfer at the surface of the material but by the velocity at which the explosive material will propagate the shock wave.

Detonation differs from other forms of combustion in that all the important energy transfer is by mass flow in strong compression waves, with negligible contributions from other processes (such as heat conduction) which are so important in flames. The leading part of a detonation front is a strong shock wave propagating into the explosive. This shock heats the material by compressing it, thus triggering a chemical reaction and a balance is attained such that the chemical reaction supports the shock wave propagation. In this process, material is consumed much faster than in a flame, making detonation easily distinguishable from other combustion processes.

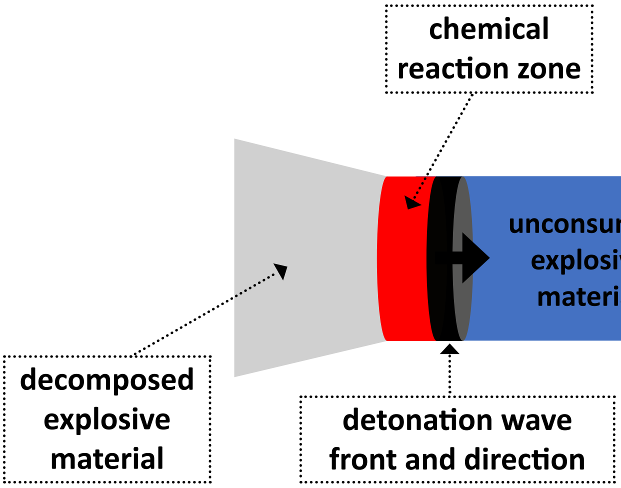

Figure 4. Schema of a detonation event in an explosive material (source: BCL ©)

NOTE. For a detonation to take place, a shock wave must move through the explosive with a velocity that is equal to or exceeds, the velocity of sound in the explosive material.

Detonation takes place within microseconds (10^{-5} sec.); it is considered a highly rapid chemical reaction. Its speed is supersonic, achieving between 1500 m/s (explosives for underground mining activities) to 10050 m/s (CL-20, currently the most powerful known chemical explosive).

A detonation creates a shock wave and pressure exceeding 100000 bar at its origin.

Substances which decompose via detonation are used as high explosives. They are also referred to as detonative explosives.

3.2.4. TRANSITION BETWEEN COMBUSTION – DEFLAGRATION – DETONATION

The transition to detonation can take place via two specific mechanisms in HMEs:

- Burning to detonation; and
- Shock to detonation.

Burning to detonation occurs when the pressure at the burning surface of an explosive accelerates the flame front beyond the velocity of sound of the explosive material under its current conditions. This would be akin to an aircraft exceeding the speed of sound in the air, the point at which the sonic boom is heard. We progress from a deflagration to a detonation, suggesting that there will be a delay to the onset. The delay to the onset of detonation depends on the nature of the explosive, charge density and conditions of confinement. For example, an unconfined explosive may simply burn or deflagrate with no detonation. If, however, the explosive undergoes combustion under confinement then the combustion gases cannot escape. This leads to a build-up of pressure at the surface of the explosive, which increases the burning rate further. If the build-up in pressure at the surface of the explosive accelerates the burning rate to the velocity of sound in the explosive material, then detonation will occur. This is the reason why secondary or tertiary explosives that are confined and are exposed to a fire may detonate.

Initiation by shock wave is used to detonate secondary explosives with primary explosives. In a shock to detonation there is no requirement to precede with a flame front through a burning process. Instead, a high velocity shock wave generated by the ignition source is responsible for the detonation formation process. As the shock wave travels into the explosive, particle compression and adiabatic heating occurs at the shock front. Adiabatic heating and compression liberate energy as the explosive decomposes, thereby accelerating the shock wave further. At some point the velocity of the shock wave may exceed the velocity of sound in the explosive material and detonation will occur. The shock wave will be required to travel a distance along the explosive (millimetres or centimetres even) before it becomes self-propagating but, unlike a burn to detonation, the delay is in microseconds.

3.3. PHYSICAL CHARACTERISTICS OF EXPLOSIVES

The information provided in this sub-section enables an assessment of the stability and sensitivity of an explosive, allowing the potential hazards and risks to be evaluated. Knowledge of the physical characteristics are essential when assessing explosives.

NOTE. Understanding an explosive's sensitivity to stimuli such as impact or friction is essential for safe handling. Sensitivity helps to determine appropriate render safe procedures.[17]

NOTE. Knowledge of an explosive's strength determines the necessary and appropriate protection measures that must be put in place. To achieve comparability, an explosive's strength can be given as a TNT equivalent. The TNT equivalent is not an international system of unites (SI) conform unit of measurement. For instance, black powder has a TNT equivalence of 0.2–0.4, RDX has a TNT equivalence of 1.5.

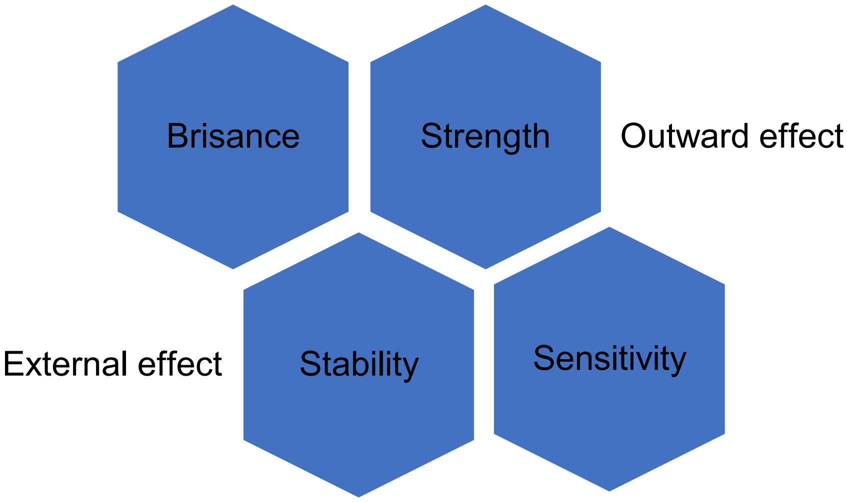

Figure 5. Properties of an explosive (source: GICHD ©)

3.3.1. BRISANCE

Brisance indicates an explosive's shattering ability. Its two main parameters, alongside gas yield and heat of explosion, are detonation velocity and loading density. Loading density is the ratio between explosive weight and the amount of space in which an explosive is detonated (compactness).

High brisance explosives are used in military high explosive applications. Low brisance explosives are used in commercial applications such as quarrying, to separate and lift / heave rock from the surrounding area rather than shatter it.

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[17] IMAS 04.10 Render Safe Procedure (RSP): the application of special EOD methods and tools to provide for the interruption of functions or separation of essential components to prevent an unacceptable detonation.

3.3.2. STABILITY

Stability includes both physical and chemical stability. Chemical stability is paramount in evaluating the expected service life of an explosive.

Chemical stability or thermodynamic stability defines the resistance or sensitivity to the decomposition of the chemical structure. A compound that can exist unaltered and unaffected by time is said to be stable.

Physical stability is the ability to remain physically unchanged over time under specified, foreseeable conditions during manufacture, storage, handling and use. Physical stability is of great importance for solid propellants where cracks in the structure increase the surface area, leading to uncontrolled and unpredictable burning. In high explosives such as TNT in artillery shells, cracks in the filling can lead to inadvertent detonation due to the huge setback forces generated during firing.

NOTE. Reactivity is the responsiveness of a substance in terms of stability. A substance is referred to as being less stable when its reactivity is high. Some explosives (for instance picric acid) generate impact-sensitive metal salts within their metal containers when reacting with the metal casing. Copper and brass casings are particularly problematic with some explosive compositions.

3.3.3. STRENGTH

The strength is determined by the gas volume produced and the energy (heat) created by the explosion as well as the detonation velocity. Gas volume determines how much work can be done by an explosive. The heat of the explosion determines the work capacity of an explosive. In general, secondary explosives generate far more heat than primary explosives. A trade-off between gas volume and heat of explosion is used to achieve the desired performance of an explosive. For example, commercially used ammonium nitrate-fuel oil mixtures produce high gas volume but low heat and are therefore useful for blasting work in quarries or mines when rocks must not be shattered. Military explosives like PETN with a high gas volume and a high gas yield are used when an object must be shattered, for instance when destroying concrete bridges.

3.3.4. SENSITIVITY AND SENSITIVENESS

Sensitivity classifies how an explosive can be initiated by external stimuli. Stimuli of importance with regard to explosives are electrostatic discharge (spark), friction, heat and flame, shock and impact. Sensitivity is therefore used to indicate the reliability of the function of an explosive, which is important for handling safety and to determine limitations in the application of an explosive.

Sensitiveness should be distinguished from sensitivity since sensitiveness refers to the accidental initiation of an explosive and the probability of initiation from unwanted stimuli. Since HMEs are not standardised, an understanding of their sensitiveness is hugely important for explosive safety.

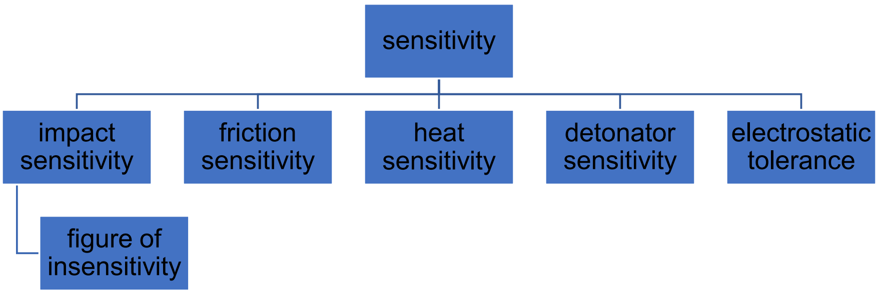

Figure 6. Overview of relevant sensitivities used to describe an explosive's behaviour (source: GICHD ©)

IMPACT SENSITIVITY

Impact sensitivity indicates sensitivity to mechanical impact. The physical unit used is Newton[18] by metre [N m] or Joule [J]. Impact sensitivity is determined under laboratory conditions. A weight is dropped on an explosive sample until the activation energy induced by (increasing) fall height is sufficient to cause the sample to decompose or explode.

The larger the numeric value, the higher the required impact introduced by the initiation energy. TNT has an impact sensitivity of approximately 15 J.[19] In theory, at sea level, a weight of 1.52 kg dropped from a 1-metre height onto a defined TNT sample would cause a reaction. For tetrazene, a primary explosive, the value is within a range of 100–200 g dropped from a 1-metre height which equals 1–2 J. Potassium chlorate–paraffin HME has an impact sensitivity of 2.6 J.[20]

Military explosives are required to be insensitive to bullet impact, a very demanding requirement designed to increase safety.

FRICTION SENSITIVITY

Friction sensitivity indicates sensitivity to mechanically induced friction. Air and impurities (such as grit) are present in any solid or liquid explosive mixture. When a stimulus is applied to a solid HME, such as that experienced during grinding (compression and friction), then pockets of air between particles are compressed. This compression leads to adiabatic heating of 400°C–500°C and the formation of 'hotspots', which may only last for a fraction of a second. Hotspots are volatile reactions at the microscopic crystalline level, their size is 10^{-3} to 10^{-5} mm. These hotspots can raise the temperature of an HME above its ignition temperature, resulting in deflagration or detonation if the energy generated by the hotspots is greater than the energy lost to the surroundings in that period. The same can be said for the presence of impurities. If these impurities are small and sharp / piercing, then only the smallest amount of friction or impact energy is required to produce a hotspot (where localised energy is generated at the interface between impurity and the explosive particle). Some HME compositions (such as TATP or potassium chlorate–sulphur) can thus be extremely sensitive and ignited by the lightest of blows.

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[18] Newton is the standardised physical unit of measurement for force.

[19] 1 Newton equals 102 grammes weight at sea level.

[20] Determined under laboratory conditions, there will be deviations.

NOTE. Friction can be introduced during the transport of an improvised explosive. The goal must be to exclude or at least minimise external influences on the HME.

The physical unit of friction sensitivity is a Newton [N]. Friction sensitivity is determined under laboratory conditions by placing weights onto explosive samples. The weight used when the sample starts to deflagrate, crack or explode, expresses the level of friction sensitivity. The larger the numeric value (the weight), the higher the resistance of the explosive to friction-induced initiation.

For example, TNT has a friction sensitivity of approximately 353 N. For tetrazene, a primary explosive, the figure is within the range of 5–8 N.

WEIGHT kg	FORCE N	KINETIC ENERGY	
		J/N m	J/N m
	at sea level	weight dropped from 1-metre height	weight dropped from 2-metre height
0.1	0.981	0.981	1.962
0.2	1.962	1.962	3.924
0.3	2.943	2.943	5.886
0.4	3.924	3.924	7.848
0.5	4.905	4.905	9.81
0.6	5.886	5.886	11.772
0.7	6.867	6.867	13.734
0.8	7.848	7.848	15.696
0.9	8.829	8.829	17.658
1	9.81	9.81	19.62
1.5	14.715	14.715	29.43
2	19.62	19.62	39.24
3	29.43	29.43	58.86
4	39.24	39.24	78.48
5	49.05	49.05	98.1
10	98.1	98.1	196.2
20	196.2	196.2	392.4
30	294.3	294.3	588.6
100	981	981	1962

Table 5. Overview of resulting force and energy created by falling weights

HEAT SENSITIVITY

Heat sensitivity measures sensitivity to thermal-induced energy before decomposition or detonation occurs. There are different measurement methods, where an explosive is exposed to heat by flames, sparks, red-hot objects or the initiating flame from a black powder safety fuse.

Apart from the induced thermal energy, the decomposition process is affected by the degree of confinement. The greater the degree of confinement, the faster the decomposition process.

The term 'deflagration point' is used to indicate the temperature at which an explosive begins to deflagrate.

EXAMPLE: FACTORS INFLUENCING HEAT SENSITIVITY AND UNINTENDED INITIATION

Because of the characteristics of hotspots regarding size and lifespan, more energy / heat is required to initiate an explosive via hotspots than from a permanent exposure to flame or red-hot steel. For instance, PETN, a secondary explosive, has an ignition temperature via hotspots between 400°C and 430°C, while the ignition temperature by a permanent heat source (heat sensitivity) is greater than 205°C.

Additives such as tinder or fuel can lower and promote an HME's heat sensitivity. For instance, potassium chlorate compositions are prone to accidental initiation. The first reason is the low melting point (356°C) and decomposition temperature (< 400°C) of potassium chlorate itself. The second is the ignition temperature of the fuel used – the lower the ignition temperature of the fuel, the more sensitive the composition. The addition of sulphur (melting point of 119°C) lowers the ignition temperature of a potassium chlorate–sulphur composition to 220°C. Organic fuels tend to trigger ignition at (or close to) their thermal decomposition temperature. Lactose and diesel provoke ignition temperatures of 195°C and 230°C respectively. The third reason is the presence of impurities that find their way into the composition during manufacture, whether they be substances such as acids, or low melting point solids such as sulphur. Such impurities can lower the melting point further and lead to instability.

CAP (DETONATOR) SENSITIVITY

Cap sensitivity measures the ability of being detonated by a single blasting cap or detonator. There are different measurement methods and tests used.

Cap sensitivity not only depends on an explosive's mixture or composition but can be influenced by its density as well.

ELECTROSTATIC TOLERANCE

Electrostatic tolerance measures sensitivity to initiation by electrical emissions. These can result from an electrostatic discharge, an electronic contact closure or an electric arc.

FIGURE OF INSENSITIVITY (FoI)

FoI is an international standardised approach to express the resistance of an explosive to impact-induced ignition. The lower the value of an explosive's FoI, the more sensitive the explosive. The secondary explosive RDX is used as the reference standard explosive for determination of the FoI. The FoI of RDX is defined as 80.

The FoI is used to classify explosives: **very sensitive** (FoI less than or equal to 50), **sensitive** (FoI greater than 50 and less than 100) and **comparatively insensitive** (FoI greater than 100).

FIGURES OF INSENSITIVITY	
very sensitive	FoI < = 50
sensitive	50 > FoI < 100
comparatively insensitive	FoI > 100

Table 6. Overview of figures of insensitivity

For instance, TNT has an FoI of 152, tetrazene has an FoI of 13. An improvised mixture such as potassium chlorate–sugar can have an FoI anywhere between 30 and 67, depending upon the type of sugar and percentage mix. As such, a potassium chlorate HME can present sensitive or very sensitive characteristics.

Image 20. RDX (source: Bundeswehr CBRN Defence Command ©)

3.3.5. OXYGEN BALANCE

The oxygen balance indicates the amount of molecularly bound oxygen that remains after complete decomposition or, alternatively, the amount of oxygen that is missing to ensure complete decomposition. A negative oxygen balance leads to the formation of toxic gases such as carbon monoxide or sulphur monoxide. If the balance is positive, no toxic gases are formed.

NOTE. The oxygen balance refers to a pure explosive. Regardless of the influence of a well-adjusted oxygen balance on the gases produced, the presence of impurities, especially in HMEs, can lead to the formation of hazardous and toxic gases.

3.3.6. CONFINEMENT

Confinement is known to have a significant influence on the reaction of some explosives to an external heat-related stimulus. Confinement does not allow the gaseous products of combustion to escape, thereby increasing the pressure at the surface of the explosive. This leads to faster burning rates until a critical point is reached whereby deflagration or detonation occurs. Some explosive matter has the tendency to combust when not confined.

Under appropriate conditions (and depending on the heat sensitivity of an explosive), confinement can force secondary explosives exposed to heat to deflagrate or explode, due to increasing gas pressure within the confinement (e.g. a shell casing). For example, when exposed to heat, this effect can cause confined TNT to deflagrate or explode while unconfined TNT will likely combust without an explosive effect. This effect of confinement and heat on explosives is known as hot cook-off.

EXAMPLE: IMPACT OF CONFINEMENT

ILLEGAL APPLICATION:

Black powder has been found in filled inert training hand grenades. The confinement of the hand grenade's body is sufficient to achieve a sudden increase in pressure generated by the combustion gases trapped inside the cast steel body. When the pressure exceeds a critical level, the cast steel body will fracture and produce a lethal fragmentation pattern. The same can be said for improvised pipe bombs where black powder is initiated within the confines of a sealed steel tube.

Confinement is used for many types of improvised explosive device to improve performance.

ACCIDENT:

Self-initiation is often observed when confined ammunition (e.g. artillery shells) is exposed to high levels of heat. In the case of ordnance which is caught in a fire or exposed to extreme heat, internal pressure increases and can result in deflagration or detonation.

This effect poses a significant threat to first responders as no reaction time can be specified between the start of the fire and the start of decomposition.

WARNING. These effects of confinement reduce the usable time for firefighting.

DISPOSAL PROCEDURES:

Cutting ordnance, such as artillery shells or aerial bombs, with explosive cutting charges is a common low order procedure.[21] The cutting effect of the charge causes a gap in the ammunition casing. Usually, the remaining energy of the cutting charge causes the explosive filling to deflagrate or to combust. When combustion occurs, a transition to deflagration or detonation can take place when the gas yield in a cut casing is higher than the amount of gas that can escape via the cut gap.

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[21] Explosive ordnance disposal technique applied to achieve safety of an item of ordnance by causing no explosive effect or by causing a significantly lower explosive effect than the effect which the ammunition was designed for.

3.3.7. CONSIDERATIONS REGARDING PHYSICAL CHARACTERISTICS OF HMEs

Physical characteristics are equally as important to HMEs as they are for military and commercial explosives. However, the lack of knowledge regarding the stability and sensitivity of HMEs used in improvised explosive devices poses a significant threat to MA organisations.

As HMEs are produced with whatever raw materials and equipment are available to the maker, their sensitivity and stability are not constant, but influenced by a variety of factors. Reliance focusing on laboratory figures, as is practiced with industrially produced explosives, is not therefore recommended. HMEs are likely to underperform in terms of explosive strength quoted in laboratory figures (since density of loading is generally difficult to replicate) but will likely deflagrate or detonate more readily given the conditions of manufacture.

The ability and capability (also using technical support) to recognise the kind of HME in question, knowledge of its precursors and an understanding of which additives or impurities it could contain, enables MA organisations to conduct a risk assessment based on the expected physical properties and characteristics of a particular type of HME. This provides the opportunity for assessing possible **safe** and **appropriate** courses of action for its render safe.

4. CHEMICAL PRECURSORS

This section identifies chemical precursors for HMEs and their properties, including information on explosive and non-explosive hazards.

NOTE. As most of the chemicals mentioned in this section have legal applications, their presence does not automatically indicate their use in HME production. It is the presence of several chemicals that would lead to this assumption. For example, ammonium nitrate on its own may be of legitimate use, but the presence of fuel oil or aluminium powder in the same facility may suggest possible HME manufacture. The presence of both hydrogen peroxide and acetone would also raise questions since these are key precursors for the manufacture of organic peroxide explosives.

NOTE. Information on the reactivity of chemicals presented here is not exhaustive. This section focuses on the types of chemicals frequently encountered in an HME environment; detailed information is accessible via a chemical's safety data sheets.

HINT. Comprehensive and updated information on chemicals can be found in chemical substance databases, using chemical safety data sheets (SDS) or laboratory chemical safety summary datasheets (LCSS). A large variety of sources can be found using the internet. Two of the online sources consulted to support this chapter are listed below.[22] Both sources are considered to be fully comprehensive and offer a good level of detail. They are open source and are thus available at no cost.

SDS source	Databases on hazardous substances (GESTIS)
LCSS datasheet source	PubChem National Library of Medicine

Image 21 shows TNT contamination of soil by a shell that was shattered by a low order disposal procedure. By consulting a safety data sheet for TNT (example: TNT SDS), knowledge about specific hazards posed by this explosive (e.g. physical properties, toxicological data, toxic effects, first aid measures in case of inhalation or absorption, or procedures for safe handling) can be obtained.

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[22] Section 16 *Further references* lists additional sources.

Image 21. TNT contamination of soil (source: GICHD ©)

The precursor chemicals presented here are mainly encountered in one of two types of condition: as a pure laboratory-grade chemical or as one ingredient of an industrially processed product, such as ammonium nitrate in fertilisers or aluminium powder in paints. This overview focuses on the use of these chemicals for HME and their explosive and non-explosive hazards, without discussing their origin. Regarding the HMEs and improvised compositions presented below, neither their effectiveness nor the value of their applications are evaluated. The intention here is to provide information about their characteristics and their hazards.

NOTE. Unless otherwise stated, the information provided refers to the pure chemical condition.

WARNING. Substances that produce flammable vapours that may deflagrate or detonate when exposed to an increase in pressure, should not be confined to containers.

WARNING. Absorption, inhalation or ingestion of vapours, liquids or solid components of most of the substances listed may lead to poisoning or may be carcinogenic. Their immediate or long-term effects should not be underestimated. Only possible acute reactions, but not long-term damage, are listed. The lethal dose is not considered. This detailed information can be found in regularly updated chemical substance databases.

The Globally Harmonized System of Classification and Labelling of Chemicals (GHS), developed by the United Nations, defines and classifies the hazards posed by chemical products, and communicates health and safety information on labels and safety data sheets. A goal of the GHS is to define a globally applicable set of rules for classifying hazards as well as the format and content of warning labels. The threshold criteria for GHS classification are health hazards, physical hazards and environmental hazards.

HINT. Regional and / or national warning labels exist in various forms. These should be explored by mine action (MA) staff, based on the country / region they are working in or the country / region of manufacture.

Based on its properties, a chemical's packaging can be marked with one or more GHS hazard pictogram. Every pictogram symbolises a warning linked to specific hazards. For example, the pictogram GHS 08 warns of systemic health hazards. These systemic health hazards are respiratory sensitisation, aspiration hazard, carcinogenicity, germ cell mutagenicity or reproductive toxicity and specific target organ toxicity. The GHS hazard statements (H) specify the initial warning provided by a GHS hazard pictogram and the GHS precautionary statements (P) specify actions to counter these hazards.[23] The statement, hazard and precaution are documented in a chemical's safety data sheet. GHS hazard pictograms are listed in Table 7 below.

NOTE. If GHS classification(s) exist(s) for a chemical, the GHS hazard pictogram(s) addressing the specific hazards is / are included as information in this chapter.

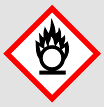
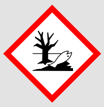
	GHS 01 EXPLODING BOMB • unstable explosive
	GHS 02 FLAME • flammable chemical or mixture
	GHS 03 FLAME OVER CIRCLE • oxidising chemical or mixture
	GHS 05 CORROSION • corrosive chemical category 1
	GHS 06 SKULL AND CROSSBONES • toxic chemical category 1–3
	GHS 07 EXCLAMATION MARK • toxic chemical category 4 • irritant chemical category 2–3 • lower systemic health hazard
	GHS 08 HEALTH HAZARD • systemic health hazard
	GHS 09 ENVIRONMENT • hazard for the environment

Table 7. List of GHS pictograms and their meanings

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[23] A comprehensive, detailed overview of the hazard categories and listed H codes and P codes can be found here: https://sitem.herts.ac.uk/aeru/iupac/docs/GHS_EU_Poster.pdf

EXAMPLE: USE OF SAFETY DATA SHEETS AND GHS CLASSIFICATIONS

Hydrogen peroxide is classified by the GHS as an oxidising agent with corrosive and irritant properties. This leads to containers or packaging including hydrogen peroxide being marked with three GHS hazard pictograms:

Consulting the safety data sheet for hydrogen peroxide, the following GHS hazard statements (H) are provided related to its specific hazards:

- H271: May cause fire or explosion; strong oxidiser
  [Danger oxidising liquids; oxidising solids]
- H302: Harmful if swallowed
  [Warning[24] acute toxicity, oral]
- H314: Causes severe skin burns and eye damage
  [Danger skin corrosion / irritation]
- H332: Harmful if inhaled
  [Warning acute toxicity, inhalation]

Precautionary statement codes provided by the SDS:

P210, P220, P221, P260, P261, P264, P270, P271, P280, P283, P301+P312, P301+P330+P331, P303+P361+P353, P304+P312, P304+P340, P305+P351+P338, P306+P360, P310, P312, P321, P330, P363, P370+P378, P371+P380+P375, P405 and P501

- P210: Keep away from heat, hot surfaces, sparks, open flames and other ignition sources – No smoking
- P220: Keep away from clothing and other combustible materials
- P221: Take any precaution to avoid mixing with combustibles/...
- P260: Do not breathe dust / fumes / gas / mist / vapours / spray
- …

The hazard statements and the precaution statements in a chemical´s SDS provides comprehensive information on the hazards posed and the required safety measures.

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[24] Danger denotes hazards not connected to specific actions; warning denotes hazards connected to specific actions.

It is sometimes not possible to identify the GHS data on a chemical's packaging / container. Table 8, below, proposes an approach with regard to a first classification of unmarked chemicals.

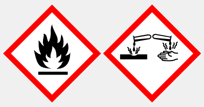
SOLID CHEMICAL	
LIQUID CHEMICAL	As above and including: 

Table 8. The approach with regard to a first classification of unmarked chemicals

Hereinafter, chemicals and HMEs are presented with a focus on information considered to support the mitigation of risks. Given the information available, the content selected here is not exhaustive. When available, the information will include:

- Name, formula, abbreviation(s) and synonym(s);
- Image and GHS hazard pictogram(s);
- Industrial(legal) and private applications;
- Appearance;
- Chemical behaviour including:
  - Flammability;
  - Promotion of existing fires;
  - Hazard of dust explosion;
  - Violent / explosive reactions when in contact with other substances;
  - Corrosive or caustic properties;
- Toxic behaviour including:
  - Risks such as irritation, disorder or severe damage to mucous membranes, skin, eyes, lungs, respiratory tract, blood, inner organs or the central nervous system;
- Materials not to be used / to be used for packaging (for instance due to reactions between the matter and the packaging material);
- Means of firefighting not to be used / to be used, such as water, water jet spray, fire extinguishing foams, fire extinguishing powders or carbon dioxide (CO_2) fire extinguishing systems;
- Hazard level with regard to water supplies.[25]

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[25] Hazardous to water supplies defines the grade of toxic effect on aquatic life if a chemical enters the water cycle. This includes long-lasting effects and long-term hazards.

4.1. FUNDAMENTALS ON PHYSICAL PARAMETERS

This sub-section presents an overview of physical parameters influencing an HME's brisance, strength, stability and sensitivity.

INGREDIENT RATIO

The ratio between fuel and oxidiser is important for oxygen balance, as it determines whether the amount of oxygen in the explosive is sufficient for complete oxidation. The most efficient explosive mixtures are those with an oxygen balance of zero, or as close to zero as possible (for example, ethylene glycol dinitrate and nitroglycol). An ideal oxygen balance guarantees complete decomposition of the HME and the reduction in production of toxic gases such as carbon monoxide or nitrogen oxide, which occurs when there is insufficient oxygen available (a negative oxygen balance).

The ingredient ratio required in an explosive is determined via a stoichiometric[26] calculation. For example, toxic gases as a by-product of an explosive's use are not desirable in commercial applications such as quarrying and mining. As such, stoichiometry will be used to determine the ratio of chemicals that produce the least toxic gases.

DEGREE OF MIXING

The degree of mixing creates the prerequisite for homogeneous decomposition. Poorly mixed improvised explosives may decompose partially or in an uncontrolled manner. Therefore, ingredients may be scattered, an HME may not react at all or be unpredictable in its combustion or deflagration behaviour. Furthermore, particularly sensitive hotspots can appear within an improvised explosive during mixing, which may lead to unintended detonation.

⚠ **NOTE. A partial detonation of HME can create further hazards. A safe waiting period following a partial detonation should be observed[27], usually 30 minutes. Explosive evaluation should take into account that remnants of improvised explosives can be scattered across the disposal site, leading to the need for further clearance steps and potential hazards.**

⚠ **WARNING. Although identical oxidisers and fuels can be employed across an entire batch of HME, the physical characteristics of each separate main charge may still differ.**

DENSITY

Density denotes the degree of compactness of a substance. Density influences an explosive's brisance significantly. An optimised density ensures maximum detonation velocity. A maximised density does not necessarily equate to maximum detonation velocity. If an HME's density is too high, some improvised explosives may become harder to initiate from external stimuli (such as flame or shock). For some explosives produced industrially, this effect is known as 'dead pressing'. For example, tetrazene, mercury fulminate, DDNP and peroxide-based primary explosives are dead-pressed very easily, causing reliability issues.

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[26] Chemical calculation of the mass and volume of substances participating in a reaction based on the reaction equation.

[27] More information regarding waiting time can be found in the GICHD's *Improvised Explosive Device Clearance Good Practice Guide*, Chapter 3 – Improvised Explosive Device Disposal – Section 1.4 General Principles, Geneva, 2020.

SURFACE AREA (OF THE EXPLOSIVE)

As the oxygen required for an explosive's detonation is bound within the explosive, the amount of explosive that can decompose per unit of time is linked to the affected surface area of the explosive only. As a result, increasing an explosive's surface area will increase sensitivity and reaction rate.

PARTICLE SIZE / PARTICLE SHAPE

The particle size affects an explosive's decomposition rate significantly. As the particle size decreases, the burning rate increases. For an explosive with the ability to transition from combustion to explosion, the particle size (in close coordination with confinement) steers the delay between ignition and detonation. In the case of propellants, the particle size is one parameter that regulates the burning rate. With a decreasing particle size, less energy is required to reach an explosive's ignition temperature, influencing its initiation process as well. Therefore, decreasing particle size makes an explosive more sensitive and easier to initiate. A decreasing particle size allows a better degree of mixing, and fuels can be better blended with the oxidiser leading to a higher brisance, amongst other effects.

The size of an explosive's surface area is not only dependent on particle size but also on its shape. The same explosive with flake-shaped particles has a larger volume to surface area ratio than one with ball-shaped particles of the same size and volume and will have better reactivity. This is due to the fact that a sphere is the geometric body with the smallest surface area in ratio to its volume.

WARNING. In general, a decreasing particle size will increase sensitivity.

CONFINEMENT

Confinement can lead to the transition from combustion to deflagration / detonation. In general, confinement accelerates an improvised explosive's decomposition rate as the evasion of pressure is delayed, hampered or even blocked. The greater the degree of confinement and the more resistant the confining material to energetic effects of decomposition, the higher the probability that the confined explosive will deflagrate or detonate.

CHARGE GEOMETRY AND CRITICAL DIAMETER

To ensure an explosive's decomposition, the charge geometry must correspond at least to the critical diameter of an improvised explosive. The critical diameter is the minimum diameter of a (cylindrical) charge for which detonation of a high explosive still occurs. The critical diameter is very much influenced by the chemical structure of an explosive. Critical diameters for a variety of explosives can be found in relevant literature; they vary considerably, even for the same type of explosive. Among other things, the critical diameter is heavily affected by confinement, particle size, detonation velocity, density or ambient temperature of unreacted explosive. Under laboratory conditions, the critical diameter of ammonium nitrate–fuel oil is 5 cm to 6.35 cm, many times greater than that required for TNT (2mm to 1 cm).

APPEARANCE

In contrast to military explosives, which are mostly readily identified as one uniform component in solid form, the majority of HMEs comprise a mixture of oxidiser and fuel. They can also be solid or liquid. As such, HMEs are more likely to appear in different colours, particle sizes and with varying odours than are military explosives.[28]

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[28] Typical appearances, including images (if available), are listed with the corresponding chemicals and compounds, below.

Image 22. Appearance of an unknown HME used in a main charge (source: FSD ©)

Image 23. Appearance of an unknown HME used in a main charge (source: BCL-YMACC ©)

4.2. ACIDS

This sub-section presents acids that are commonly encountered in the manufacturing of HME.

Acids are required to purify or synthesise substances; they can act as reactants or catalysts. Both organic and inorganic acids are used in the production of HME. The concentration of acids differs depending on the source. For some procedures, a minimum concentration of an acid is required. For instance, acids used for nitration reactions require a concentration from 65% up to 99%. Usually, highly concentrated acids are preferred by the manufacturer (strong acids like sulphuric acid, nitric acid or hydrochloric acid).

WARNING. Acids will burn skin and destroy clothing. If any acid is spilled, it should be washed away with a large quantity of water, and medical attention should be sought as soon as possible. The fumes produced by an acid must not be inhaled.

MA staff may encounter acids at abandoned manufacturing facilities, abandoned storage sites or as manufacturing waste. Acids can be toxic and hazardous to the environment. In general, acids emit toxic fumes and are corrosive to organic and inorganic materials. No water should be mixed with acids, since this can lead to a violent exothermic reaction. The addition of metals to concentrated acids can also lead to a violent exothermic reaction.

NOTE. If an acid must be diluted, the acid should be added to the water, in small quantities and very slowly.

WARNING. Acid residues in an HME can lead to spontaneous self-ignition, for instance in the case of nitrocellulose and some dynamites.

ACETIC ACID – ORGANIC [$C_2H_4O_2$] OR VINEGAR (DILUTED), HYDROGEN ACETATE

Image 24. Acetic acid
(source: Bundeswehr CBRN Defence Command ©)

Acetic acid is important in the chemical industry. It is widely used as a descaling agent, a cleaning agent and in less concentrated forms (i.e. vinegar) for household use. Vinegar rarely contains more than a 5% acid concentration. Acetic acid is one possible precursor for HMTD and TATP.

Acetic acid is a colourless liquid which crystallises at 17°C. It has a strong, sour, vinegar-like odour. The substance is volatile and hygroscopic.

CHEMICAL BEHAVIOUR

Pure liquid acetic acid is flammable. If heated above its flashpoint, its fumes can form explosive mixtures with atmospheric oxygen.

An explosion or violent reaction can occur when acetic acid comes into contact with, for instance, hydrogen peroxide or other strong acids or oxidisers.

TOXIC BEHAVIOUR

Acetic acid has an increasingly irritating (to corrosive) effect on mucous membranes and skin as concentration increases. Severe eye and lung damage can occur when exposed to high concentrations.

Acetic acid should not be stored in containers made of brass, copper, iron or zinc. Suitable containers are made of aluminium, glass or polyethylene (PE).

Acetic acid is slightly hazardous to water supplies.[29]

NOTE. Hygroscopic means readily water-attracting. Hygroscopic substances absorb water vapours even from the air, forming a saturated solution. Hygroscopic solids begin to clump. (The surface of) a material may even plasticise or liquify if enough water is absorbed. Absorption of water can reduce reactivity and sensitivity of the substance affected.

NOTE. Flashpoint is the lowest temperature at which a volatile substance evaporates to form an ignitable mixture with air in the presence of an igneous source and continues burning after the trigger source is removed.[30]

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[29] Hazardous to water supplies defines the grade of toxic effect on aquatic life if a chemical enters the water cycle. This includes long-lasting effects and long-term hazards.

[30] Joaquín Isac-García et al., *Experimental Organic Chemistry – Laboratory Manual* (Academic Press, 2015).

CITRIC ACID – ORGANIC [$C_6H_8O_7$] OR SOUR SALT, CITRON, LEMON ACID

Image 25. Citric acid
(source: Bundeswehr CBRN Defence Command ©)

Citric acid is used to make drinks and food sour, in limescale removers, as a water softener, and in cosmetics and pharmaceutical products. Citric acid is one possible precursor for HMTD.

Citric acid is a white, odourless solid, in powder or crystal form. It is easily soluble in water, where it can result in / produce a faint citrus odour.

CHEMICAL BEHAVIOUR

Pure citric acid is a slight fire hazard when exposed to heat or flame. A violent reaction can occur when citric acid comes into contact with oxidisers, reducing agents or metals, for example. An explosive reaction may result if citric acid is mixed with metal salts.[31] Powdered citric acid can contribute to a dust explosion.[32]

TOXIC BEHAVIOUR

Citric acid can cause irritation and have a caustic effect on the eyes as well as an irritating effect on the upper airways.

Citric acid should not be stored in containers made of base metals. Containers made of glass or steel are acceptable.

There are no known hazards to water and water reservoirs from citric acid.

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[31] A metal salt is a chemical compound of a metal and an acid.

[32] See sub-section 4.4.2. *Solid fuels*.

HYDROCHLORIC ACID – INORGANIC [HCl] OR MURIATIC ACID

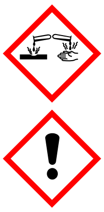

Image 26. Laboratory-grade hydrochloric acid
(source: Bundeswehr CBRN Defence Command ©)

Hydrochloric acid is important for the chemicals, pharmaceutical and galvanic industries, where it is used in highly concentrated forms for the pickling of steel (dissolving metal oxides from steel / iron surfaces). In biology, hydrochloric acid is an important component of the gastric juice of humans and animals. As a strong mineral acid, it is used as a reactant in the manufacture of HMEs.

Hydrochloric acid is a colourless-yellowish liquid with a pungent odour.

CHEMICAL BEHAVIOUR

Hydrochloric acid is highly corrosive and reacts with surrounding atmospheric oxygen, forming caustic acid fumes which are heavier than air. A violent reaction can occur when hydrochloric acid comes into contact with alkali metals and organic materials.

TOXIC BEHAVIOUR

Hydrochloric acid has an irritant and corrosive effect on the eyes, respiratory tract and skin. There is the risk of severe eye and lung damage. It produces choking fumes, which can quickly incapacitate those exposed to it. If swallowed, medical attention should be sought immediately.

Hydrochloric acid should not be stored in containers made of metals. Containers made of glass, PE or polyvinylchloride (PVC) are suitable.

Hydrochloric acid is slightly hazardous to water supplies.

NOTE. Alkali metals are lithium, sodium, potassium, rubidium, caesium and francium. Alkali metals are soft, flammable, very reactive (sometimes explosive) elements. They ignite when heated in air or in combination with oxygen, and react violently on contact with moisture to form hydrogen (which can ignite from the heat of reaction) and corresponding hydroxide smoke (corrosive). Heated alkali metals burn by themselves in atmospheric air and melt. In powder and dust form, alkali metals can self-ignite at room temperature (20°C). In general, alkali metals react very violently on contact with water. They do not sink but float and dance around on the water surface with the appearance of fire and explosions. Their reaction with water forms easily combustible hydrogen gas which can ignite, and strongly corrosive hydroxide. Explosions are possible in closed rooms / confined spaces. Corrosive mixtures that can be formed with water are still effective even when diluted.

HYDROGEN PEROXIDE – INORGANIC [H_2O_2]

Image 27. 30% hydrogen peroxide
(source: Bundeswehr CBRN Defence Command ©)

Hydrogen peroxide has a variety of applications, both in industry and in household use. It is used as a bleaching agent and disinfectant. Concentrated hydrogen peroxide is used in propellants, for instance liquid rocket fuel, and to produce improvised organic peroxide explosives such as HMTD, methyl ethyl ketone peroxide (MEKP) and TATP.

Depending on its concentration, hydrogen peroxide goes from a colourless to a pale blue liquid. It has a low volatility.

CHEMICAL BEHAVIOUR

Hydrogen peroxide itself does not burn but reacts so violently with flammable substances that it can cause them to ignite, sometimes without a further ignition source. It can significantly increase the potency of an existing fire, given the amount of oxygen in its structure. Hydrogen peroxide with a concentration > 8% should not be allowed to come into contact with fabrics or leather.

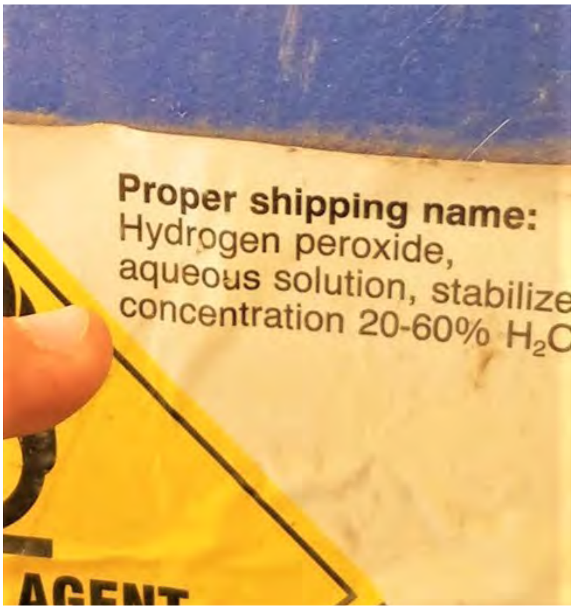

Image 28. A hydrogen peroxide container - field finding
(source: GICHD ©)

An explosion or violent reaction can occur when hydrogen peroxide comes into contact with, for instance, acetone, acetic acid, cotton fibres, flammable substances, glycerine, hydrazine, metallic powders, nitric acid, nitromethane, sulphuric acid or wood.

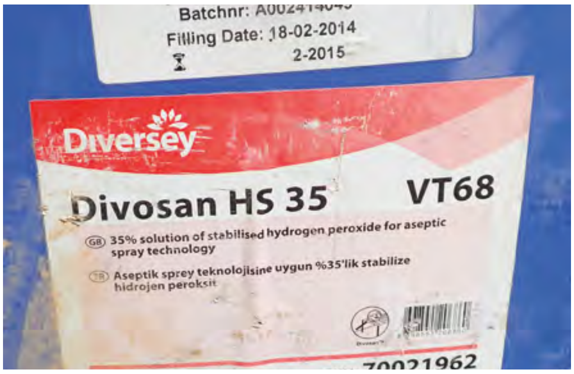

Image 29. A drum of hydrogen peroxide - field finding
(source: CAR ©)

TOXIC BEHAVIOUR

Depending on its concentration, hydrogen peroxide can cause irritation and have a corrosive effect on skin, mucous membranes, eyes, and causes inflammatory changes in the respiratory tract. In extreme cases, it causes lung damage due to a high concentration of vapours / aerosols. If swallowed, hydrogen peroxide can cause fatal gas bubbles in the blood.

Hydrogen peroxide should not be stored in containers made of brass, bronze, copper or iron. Containers made of glass, PE (< 60% concentration) or PVC (< 60% concentration) are acceptable.

Hydrogen peroxide is slightly hazardous to water supplies.

NOTE. Hydrogen peroxide is a powerful oxidiser since its chemical structure contains 94% mass percentage oxygen. Any container of hydrogen peroxide marked as having above 35% concentration should be considered suspicious and be reported.

WARNING. Contact of hydrogen peroxide with organic chemicals (e.g. formic acid) can lead to violent explosive decomposition reactions.

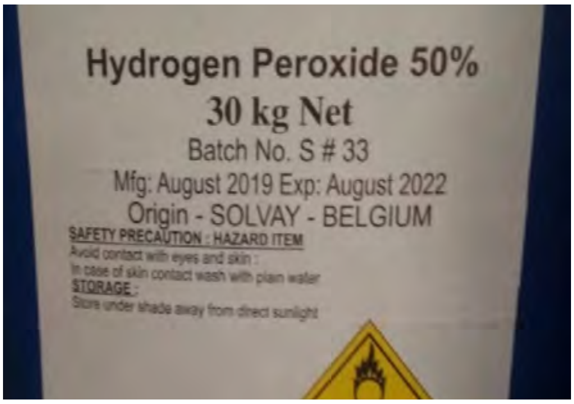

Image 30. 50% hydrogen peroxide observed in Yemen
(source: BCL ©)

NITRIC ACID – INORGANIC [HNO_3] OR AQUA FORTIS, EAU FORTE, HYDROGEN NITRATE, RED FUMING NITRIC ACID (RFNA), WHITE FUMING NITRIC ACID (WFNA)

Image 31. 65% nitric acid
(source: Bundeswehr CBRN Defence Command ©)

Image 32. 100% nitric acid
(source: Bundeswehr CBRN Defence Command ©)

Nitric acid has wide usage in the chemical industry. It is fundamental in the production of many explosives as the principal nitrating agent. It is used to produce nitrates and fertilisers, to separate gold and silver and it is used in the galvanic industry and in the paint industry (nitro paints). Highly concentrated nitric acid is used as an oxidiser in liquid explosives (for instance hellhoffite) or in liquid rocket fuel (RFNA / WFNA). Nitric acid used in the production of explosives has a concentration of between 70% and 99%. The greater the concentration, the more volatile the nitration reaction.

Organic nitrates – the nitrate esters – are compounds that can decompose explosively. Therefore, the esters of polyalcohols can be / are used as explosives.

HINT. The presence of a nitrate source and a strong mineral acid can indicate the manufacturing of nitric acid.

Nitric acid, depending on its concentration, is colourless-yellowish. Under sunlight, it decomposes and turns red. Nitric acid has a pungent odour. It evaporates to give reddish-brown fumes.

CHEMICAL BEHAVIOUR (CONCENTRATION > 65%):

Nitric acid is not flammable but can significantly increase an existing fire. It increases the fire hazard when in contact with flammable substances. Nitric acid is sensitive to the surrounding air. It is a strong oxidiser and a strong acid.

An explosion or violent reaction can occur when nitric acid comes into contact with acetic acid, acetone, ammonia, flammable substances, fuel oil, hydrazine, hydrogen peroxide, metal powders, nitromethane, organic substances with large surfaces (for instance fine sawdust) and potassium chlorate.

⚠ **WARNING. If nitric acid comes into contact with sawdust, wood wool, cleaning wool, paper, cotton residues, cellulose or other finely dispersed organic materials, toxic nitrous gases (nitrogen oxides) are formed. Depending on the surrounding conditions, fires, spontaneous combustion or even explosions are possible. Gun cotton was accidentally discovered in this way when a cotton rag used to wipe up spilled nitric acid self-combusted as it began to dry out.**

TOXIC BEHAVIOUR

Nitric acid has an irritant and corrosive effect on the eyes, respiratory tract and skin. Its fumes can cause choking. Unprotected contact presents a risk of severe eye and lung damage.

Nitric acid should not be stored in containers made of base metals. Usable containers should be made of dark brown glass, PE, polypropylene (PP) or PVC.

Leakage of nitric acid into water, the sewage system or soil must be avoided, as it is severely hazardous to water supplies.

PERCHLORIC ACID – INORGANIC [$HClO_4$]

Image 33. 71% perchloric acid
(source: Bundeswehr CBRN Defence Command ©)

Perchloric acid is used as an analytical reagent and in the production of pesticides, explosives and rocket fuel.

Perchloric acid is a colourless and odourless liquid. It is hygroscopic and volatile and will create toxic and explosive vapours when in contact with air. Perchloric acid with a 50% concentration may explode if heated. This acid may decompose explosively without any recognisable cause.

CHEMICAL BEHAVIOUR (CONCENTRATION BETWEEN 50% AND 72%)

Perchloric acid is not flammable but can act as an oxygen source to an existing fire. It increases the fire hazard when in contact with flammable substances. The reaction with flammable substances can lead to self-ignition. Pure perchloric acid may explode violently when heated above 75°C.

An explosion or violent reaction can occur when the acid comes into contact with alcohol, flammable substances, sulfuric acid, coal, metals, glycerine, sawdust, nitric acid or a heat source.

TOXIC BEHAVIOUR

Perchloric acid has a highly irritant and corrosive effect on mucous membranes and skin. There is a risk of serious, irreversible damage to the eyes.

Perchloric acid should not be stored in containers made of base metals. Usable containers are those made from glass, PE, PP or PVC.

Perchloric acid is slightly hazardous to water supplies.

PICRIC ACID – ORGANIC [$C_6H_3N_3O_7$] OR 2,4,6-TRINITROPHENOL

Image 34. Picric acid
(source: Bundeswehr CBRN Defence Command ©)

Picric acid is a strong acid and a homogenous explosive that was used as one of the main explosive fillers in grenades, mortar bombs and artillery shells at the beginning of the 20th century. Given its tendency to react with metal casings (e.g. artillery shells) resulting in the formation of sensitive, explosive picrate salts, it is no longer used by the military. Today, it is mainly used in primary explosive compositions in detonators.

Picric acid is a light yellow, shiny, bitter-tasting, odourless, crystallised solid. It is hardly soluble in water but soluble in alcohol, ester, benzene and acetone.

CHEMICAL BEHAVIOUR

Picric acid is an explosive solid with an impact sensitivity of 7–8 J and a friction sensitivity of up to 353 N. It reacts by impact or friction, heating (fires) or other ignition sources with rapid decomposition and the formation of large quantities of gas.

An explosion can occur when pure picric acid comes into contact with aluminium, ammonia, metals, oxidisers in general, or potassium.

TOXIC BEHAVIOUR

Absorption of picric acid leads to irritation of the eyes and nasal mucous membranes, colouration of unprotected skin, gastrointestinal discomfort, nervous disorders and damage to the blood, kidneys and liver.

Water is an appropriate fire extinguishing agent for picric acid.

However, picric acid is significantly hazardous to water supplies, and its introduction into water, sewerage systems or soil must be prevented.

WARNING. Picric acid forms picrates with nearly every metal. Picrates have a crystal structure, nearly all have explosive properties. Picrates are more sensitive than picric acid. For less stable picrates, a crack in their crystal structure, for instance caused by shock or friction, induces sufficient energy to cause their explosive decomposition. The sensitivity of many metal picrate salts is such that they can initiate even when wet. For example, a fire in a French ammunition factory in 1916 caused molten picric acid to seep onto the concrete floor. Calcium picrate was formed and detonated during clean up, killing 170 people.[33]

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[33] Louis A. Medard, *Accidental Explosions, Volume 2: Types of Explosive Substances*, (New York: John Wiley & Sons, 1989), 739.

SULPHURIC ACID – INORGANIC [H_2SO_4] OR OIL OF VITRIOL

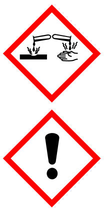

Image 35. 100% sulphuric acid
(source: Bundeswehr CBRN Defence Command ©)

Sulphuric acid is used in lead-acid batteries and some drain cleaners. It is a common catalyst used to manufacture various HMEs.

Sulphuric acid is a colourless and odourless liquid. When impure, it has a brownish colour. It is hygroscopic and not volatile.

CHEMICAL BEHAVIOUR

An explosion or violent reaction can occur when sulphuric acid comes into contact with alkali metals or metals like aluminium (decreasing particle size accelerates the reaction), flammable substances, hydrogen peroxide, chlorates, nitrates, nitric acid. A reaction with water releases toxic fumes.

TOXIC BEHAVIOUR

Sulphuric acid has a highly irritant and corrosive effect on mucous membranes and skin, with the risk of serious, irreversible damage to the eyes and lungs.

Sulfuric acid should not be stored in containers made of base metals. Suitable containers should be made of glass, PE, PP or PVC.

Sulphuric acid is slightly hazardous to water supplies.

WARNING. Mixing concentrated sulphuric acid with concentrated caustic soda (sodium hydroxide) leads to such intense heating that the container may boil over and corrosive liquid may spill out.

4.3. OXIDISERS

This sub-section gives an overview of commonly used oxidisers for the manufacturing of HME, including:

- Group of nitrates (salts and esters of nitric acid);
- Group of chlorates (salts of chloric acid);
- Group of perchlorates (salts of perchloric acid); and
- Oxidisers not belonging to one of the groups listed above.

Oxidisers are substances that are combined with a fuel to produce an energetic material. An oxidiser is a substance with an electron deficit. It provides the source of oxygen needed for an explosion, making the detonation independent from atmospheric oxygen.

The more oxygen bound in the explosive structure, the better the energetic effect. Oxidisers are therefore the significant variable affecting the manufacture of HME and the HME's subsequent physical characteristics and performance.

CHARACTERISTICS

Characteristics of interest for oxidisers are as follows:

- The compound may not be flammable in its own right, requiring a fuel to initiate the process.
- Oxidising agents are generally oxygen-rich ionic solids that decompose at moderate to high temperatures, releasing oxygen gas in the process.
- Many oxidisers are readily available, in reasonably pure form, in an appropriate particle size and at reasonable cost.
- Oxidisers increase the risk of fire when in contact with flammable substances and can significantly worsen an existing fire.
- Oxidisers can react so violently with flammable substances that they cause them to ignite, sometimes just by contact, without the need for a separate ignition source.

⚠ **WARNING. Oxidising agents can cause fires simply through contact with organic materials such as wood, paper and cardboard.**

4.3.1. GROUP OF NITRATES

Nitrates are the salts or the esters of nitric acid. They are quite insensitive to impact and friction, yet, when added to an appropriate fuel like aluminium, they can generate viable explosive mixtures. Some nitrates in their pure form can detonate if given a sufficient impulse such as a shock.

AMMONIUM NITRATE [NH_4NO_3]

Image 36. Ammonium nitrate prills
(source: Bundeswehr CBRN Defence Command ©)

Image 37. Fine ammonium nitrate
(source: Bundeswehr CBRN Defence Command ©)

Image 38. Ammonium nitrate crystals
(source: Bundeswehr CBRN Defence Command ©)

Ammonium nitrate is a white crystalline salt of ammonia and nitric acid, used widely in fertilisers, freezing mixtures (cool packs) and anaesthetics (manufacture of nitrous oxide), and is the most important raw material in the manufacture of commercial explosives. Pure, commercial grade ammonium-nitrate contains about 33.5% mass percentage nitrogen. Ammonium nitrate has a melting temperature of around 170°C, decomposes at 210°C and can burn to detonation in large quantities without confinement,[34] as in the recent case of deflagration to detonation of over 2700 tonnes of ammonium nitrate at Beirut Port, on 4th August 2020.

Ammonium nitrate is also used to modify the detonation rate of other explosives, such as nitroglycerine in the so-called ammonia dynamites, or as an oxidising agent in ammonals which are mixtures of ammonium nitrate and powdered aluminium. The vast majority of ammonium nitrate-based HME compositions are generally insensitive to initiation by detonator alone and require confinement and a booster. They have a low detonation velocity, so are unsuitable for driving anti-armour penetrators such as shaped charges and explosively formed projectiles. They are not easily initiated in small quantities but do react to a specific impulse similar to TNT. This is one reason they are used for blast-related applications.

CHEMICAL BEHAVIOUR

Ammonium nitrate itself does not burn but increases the fire hazard when in contact with combustible materials. Ammonium nitrate can significantly promote an existing fire. Dry pure ammonium nitrate can detonate but phlegmatisation with more than 3% water will prevent this from happening.

Ammonium nitrate is extremely hygroscopic and its crystals are often coated with inert substances to prevent liquefaction and caking. Pure ammonium nitrate is difficult to detonate on its own. As such, ammonium nitrate HME is generally a mixture of ammonium nitrate with an organic or metal fuel. The fuel reacts with the excess oxygen liberated during combustion to produce additional gas and heat.

⚠ **WARNING. Ammonium nitrate is wholly incompatible with chlorates, given the formation of ammonium chlorate – a spontaneous explosive, which is physically unstable in the presence of moisture.**

An explosion or violent reaction can occur when pure ammonium nitrate comes into contact with alkali metals, powdered metals (for instance aluminium), acetic acid, ammonium, combustible substances, organic substances, water, chlorates, chlorides, urea, sodium nitrate, sulphur or phosphorus.

TOXIC BEHAVIOUR

Ammonium nitrate is an oxidising substance, which is harmful if swallowed or inhaled and an irritant to the eyes, skin and respiratory system. On decomposition, it produces nitrous oxide, a poisonous by-product of combustion.

Ammonium nitrate is slightly hazardous to water supplies.

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[34] United States Environmental Protection Agency, *Chemical Advisory: Safe Storage, Handling, and Management of Ammonium Nitrate*. EPA 550-S-13-001, August 2013.

BARIUM NITRATE [$Ba(NO_3)_2$]

Image 39. Barium nitrate
(source: Bundeswehr CBRN Defence Command ©)

Barium nitrate is mainly used to produce pyrotechnics but has been used with TNT in an explosive called Baratol, or with thermite to form thermate. There is no legitimate household application.

Pure barium nitrate is a colourless, odourless, crystalline substance. It is hygroscopic and soluble in water and produces a green flame when burned with other substances.

CHEMICAL BEHAVIOUR

Barium nitrate itself does not burn but increases fire hazard when in contact with combustible materials. Barium nitrate can significantly worsen an existing fire, being an oxidiser.

An explosion or violent reaction can occur when pure barium nitrate comes into contact with ammonium nitrate, charcoal, thermite, sulphur, combustible substances or acids.

TOXIC BEHAVIOUR

Barium nitrate can have an irritant effect on skin and mucous membranes. If ingested, it can be fatal or lead to muscle cramps and damage to the blood, gastrointestinal tract and cardiovascular system.

Barium nitrate is slightly hazardous to water supplies.

LEAD (II) NITRATE [$Pb(NO_3)_2$]

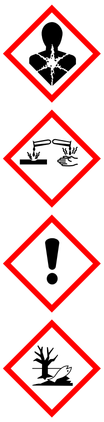

Image 40. Lead (II) nitrate
(source: Bundeswehr CBRN Defence Command ©)

Lead (II) nitrate has no industrial or household use.

Lead (II) nitrate is a grey-white, odourless, crystalline solid or powder. It dissolves very well in water and does not burn as a pure substance.

CHEMICAL BEHAVIOUR

An explosion or violent reaction can occur when pure lead (II) nitrate comes into contact with ammonium, carbon, fine metal powders or combustible organic substances.

TOXIC BEHAVIOUR

Lead (II) nitrate can lead to gastrointestinal, central nervous system and blood function disorders.

Lead (II) nitrate is highly hazardous to water supplies. Therefore, spillage into water, sewage systems or soil, even in small quantities, must be prevented.

POTASSIUM NITRATE [KNO_3] OR SALTPETRE, NITRATE OF POTASH[35]

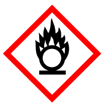

Image 41. Potassium nitrate
(source: Bundeswehr CBRN Defence Command ©)

Potassium nitrate or 'saltpetre' is the oldest recorded solid oxidiser and is a component of black powder. It is used in pyrotechnics, fertilisers and glass melts. It is also used as pickling salt in food preservation.

Potassium nitrate is a colourless-white transparent crystalline substance, with a cool-bitter taste. It is not hygroscopic. The crystals dissolve in water and in glycerine.

Image 42. An example of packaging of potassium nitrate fertiliser (source: CAR ©)

CHEMICAL BEHAVIOUR

Potassium nitrate itself does not burn but increases the fire hazard when in contact with combustible materials. Potassium nitrate can significantly promote an existing fire.

Potassium nitrate will not undergo an explosion by itself, even when a very strong stimulus is applied.

An explosion or violent reaction can occur when pure potassium nitrate comes into contact with powdered metals (e.g. potassium, magnesium) or fuels such as coal, sulphur, red phosphorus, white phosphorus or acid catalysts.

TOXIC BEHAVIOUR

Ingestion of potassium nitrate can lead to gastrointestinal tract problems, headaches, vasodilation and it may disturb methaemoglobin formation.

Potassium nitrate is slightly hazardous to water supplies.

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[35] Potash or potassium carbonate K_2CO_3 is the salt of carbonic acid.

SILVER NITRATE [$AgNO_3$]

Image 43. Silver nitrate
(source: Bundeswehr CBRN Defence Command ©)

Silver nitrate has a variety of uses in the pharmaceutical and medical industries. It is used in the galvanic industry for silver plating, for mirror silver for instance.

Silver nitrate is a colourless, white-transparent, crystalline substance that tastes extremely bitter. It is soluble in water. It dyes skin or organic tissue black after contact.

CHEMICAL BEHAVIOUR

Silver nitrate itself does not burn but increases fire hazard when in contact with combustible materials. Silver nitrate can significantly promote an existing fire.

An explosion or violent reaction can occur when pure silver nitrate comes into contact with ammonium, coal, combustible substances, hydrogen peroxide, phosphorus, powdered metals (e.g. magnesium), sulphur or nitric acid.

TOXIC BEHAVIOUR

Silver nitrate is highly toxic. It can have an irritant effect on skin and mucous membranes; in the case of oral intake of high doses it can cause gastrointestinal, cardiovascular system and central nervous system disorders.

Silver nitrate is highly hazardous to water supplies, even the introduction of small quantities into water, sewage systems or soil must be prevented.

SODIUM NITRATE [$NaNO_3$] OR SODA

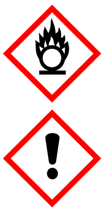


Image 44. Sodium nitrate
(source: Bundeswehr CBRN Defence Command ©)

Sodium nitrate or ‘Chile saltpetre’ is used in fertilisers, as an oxidiser for glass and enamel, and as a component for explosives, such as rocket propellants.

Sodium nitrate is a white or yellow, odourless, hygroscopic, crystalline substance, which easily dissolves in water.

CHEMICAL BEHAVIOUR

Sodium nitrate itself does not burn but increases the fire hazard when in contact with combustible materials. Sodium nitrate can significantly promote an existing fire. Heat or friction can cause it to ignite.

An explosion or violent reaction can occur when pure sodium nitrate comes into contact with powdered metals, organic substances, charcoal or sulphur.

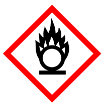
TOXIC BEHAVIOUR

Sodium nitrate exposure can lead to damage to the gastrointestinal tract and to vasodilation. In case of severe poisoning, it can disturb methaemoglobin formation in the blood.

Sodium nitrate is slightly hazardous to water supplies.

STRONTIUM NITRATE [$Sr(NO_3)_2$]

Image 45. Strontium nitrate
(source: Bundeswehr CBRN Defence Command ©)



Strontium nitrate is used in pyrotechnics to produce a red flame. It is also used in gas generators, for example in airbags.

Strontium nitrate is a colourless, white-transparent, crystalline substance. It is easily soluble in water.

CHEMICAL BEHAVIOUR

Strontium nitrate itself does not burn but reacts so violently with flammable substances that it can cause them to ignite, in some cases without any other ignition source. Strontium nitrate can significantly promote an existing fire.

An explosion or violent reaction can occur when pure strontium nitrate comes into contact with powdered metals (e.g. magnesium), sulphur and combustible substances.

TOXIC BEHAVIOUR

Strontium nitrate can have an irritant effect on skin and mucous membranes. In case of severe poisoning, for instance in the case of oral intake, potassium nitrate can lead to gastrointestinal tract problems and vasodilation and may disturb methaemoglobin formation.

Strontium nitrate must not be stored in PVC containers.

Strontium nitrate is slightly hazardous to water supplies.

4.3.2. GROUP OF CHLORATES

Chlorates are the salts of chloric acid ($HClO_3$). They are more sensitive to impact than nitrates.

BARIUM CHLORATE [$Ba(ClO_3)_2$]

Barium chlorate is used in pyrotechnics but its importance has diminished because its presence in pyrotechnic mixtures causes high sensitivity to impact and friction. Barium chlorate produces green flames.

Barium chlorate is a colourless, odourless, powder-like or crystalline substance. It is hygroscopic and soluble in water.

CHEMICAL BEHAVIOUR

Barium chlorate itself does not burn but reacts so violently with flammable substances that it can cause them to ignite, in some cases without any other ignition source. Barium chlorate can significantly promote an existing fire.

An explosion or violent reaction can occur when pure barium chlorate comes into contact with acids, combustible substances, concentrated sulphuric acid, organic substances, phosphorus, powdered coal, powdered metal or sulphur.

TOXIC BEHAVIOUR

Barium chlorate can have an irritant effect on skin and mucous membranes. It can lead to muscle cramps, cardiovascular and blood damage, and gastrointestinal tract problems.

Barium chlorate is slightly hazardous to water supplies.

POTASSIUM CHLORATE [$KClO_3$]

Image 46. Potassium chlorate
(source: Bundeswehr CBRN Defence Command ©)

Potassium chlorate is used in pesticides, explosives, fireworks and matches. Impurities such as red phosphorus, sulphur or powdered metal can lead to self-ignition and, depending on the kind of fuels and level of confinement, to detonation. As such, its use in firework compositions has diminished considerably over the years.

Potassium chlorate is a colourless-white, odourless substance that can have a crystalline, powder or granulated form. It dissolves easily in water.

CHEMICAL BEHAVIOUR

Potassium chlorate itself does not burn but reacts so violently with flammable substances that it can cause them to ignite, in some cases without any further ignition source.

Potassium chlorate can significantly promote an existing fire. Intense mixtures with flammable substances such as organic substances or metal powders can explode by friction or slight impact.

An explosion or violent reaction can occur when pure potassium chlorate comes into contact with ammonium, combustible substances, ethanol, organic acids, paraffin, petrol, potassium components, powdered metals (aluminium, magnesium, potassium) or red phosphorus.

TOXIC BEHAVIOUR

Potassium chlorate can cause strongly irritant effects on mucous membranes, especially in the eyes. It can have an irritating effect on skin.

Potassium chlorate is slightly hazardous to water supplies.

Potassium chlorate is frequently used in the manufacture of HMEs. Table 9, below, compares its sensitivity in combination with common additives (fuels) to that of other primary and secondary explosives.

EXPLOSIVE COMPOSITION	MELTING / IGNITION TEMPERATURE OR DEFLAGRATION POINT* (^{o}C)	FoI
Potassium chlorate–ammonium nitrate	< 100*	10 (with the formation of ammonium chlorate)
Mercury fulminate	165*	10
Lead styphnate	275–280*	12
Tetrazene	140*	13
Lead azide	320–360*	20
Nitrocellulose (dried @ 13.4% N)	132	23
Potassium chlorate–sulphur	220	28 (at stoichiometry)
Potassium chlorate–sugar	195	30–67 (depending on type of sugar and percentage mix)
Nitroglycerine	13 (200*)	30
Potassium chlorate–charcoal	335	35 (at stoichiometry)
Potassium chlorate–charcoal–sugar	275	35 (at stoichiometry)
Potassium chlorate–fuel oil	230	50 (at stoichiometry)
PETN	141.3 (202*)	51
RDX	213 (260*)	80
Black powder	450 (for ingredient ratio of 75 / 15 / 10)	90
TNT	80.8 (300*)	152

Table 9. The sensitivity of potassium chlorate and additives compared to other primary and secondary explosives (sorted by FoI) (source: BCL ©)

SODIUM CHLORATE [$NaClO_3$]

Image 47. Sodium chlorate
(source: Bundeswehr CBRN Defence Command ©)

Sodium chlorate is used as a bleaching agent for paper, in welding torches, as a raw material in pesticides and as a chemical oxygen generator (chlorate candles) used in mining or aviation.

Sodium chlorate is a colourless, sometimes pale yellow-white, odourless, crystalline substance. It dissolves in water and is hygroscopic.

CHEMICAL BEHAVIOUR

Sodium chlorate itself does not burn but reacts so violently with flammable substances that it can cause them to ignite, in some cases without any other ignition source. The solid product and even 30% solution in water are powerful oxidising agents.

Sodium chlorate can significantly promote an existing fire. In addition, there is the danger of explosion when it is mixed with organic substances.

An explosion or violent reaction can occur when pure sodium chlorate comes into contact with ammonium salts, combustible substances, concentrated acids, grease, nitro benzol (nitrobenzene), organic substances, oils, phosphorus, powdered metals, sulphuric acid or sulphur.

TOXIC BEHAVIOUR

Sodium chlorate has a low irritant effect on mucous membranes and skin. Absorption via the lungs or the digestive tract can lead to blood and kidney damage.

Sodium chlorate is significantly hazardous to water supplies.

STRONTIUM CHLORATE [$Sr(ClO_3)_2$]

Strontium chlorate is used in pyrotechnics to produce a red flame.

Strontium chlorate is a colourless, odourless, crystalline substance. It dissolves in water and is hygroscopic.

CHEMICAL BEHAVIOUR

Strontium chlorate itself does not burn but reacts so violently with flammable substances that it can cause them to ignite, in some cases without any other ignition source.

Strontium chlorate can significantly promote an existing fire. When heated to decomposition it emits toxic fumes of hydrogen chloride.

TOXIC BEHAVIOUR

Strontium chlorate has a highly irritating effect on mucous membranes, especially in the eyes.

Strontium chlorate is hazardous to water supplies.

4.3.3. GROUP OF PERCHLORATES

Perchlorates are the salts of perchloric acid ($HClO_4$). They are more sensitive to impact and friction than chlorates or nitrates.

AMMONIUM PERCHLORATE [NH_4ClO_4]

Image 48. Ammonium perchlorate
(source: Bundeswehr CBRN Defence Command ©)

Ammonium perchlorate is used with combustible materials in the manufacture of composite rocket propellants. It is also used in the production of explosives and fireworks.

Ammonium perchlorate is a colourless, odourless, crystalline substance but can also appear as light grey or silver-grey crystals. It is soluble in water.

CHEMICAL BEHAVIOUR

In addition to its high sensitivity to impact and friction, ammonium perchlorate is sensitive to heat and other ignition sources (e.g. strong acids). Each of these stimuli may lead to a rapid decomposition with a high gas yield.

Ammonium perchlorate itself does not burn but reacts so violently with flammable substances that it can cause them to ignite, in some cases without any further ignition source. Ammonium perchlorate can significantly promote an existing fire. Mixing ammonium perchlorate with combustible powdery substances may lead to explosions, particularly in confinement.

A violent reaction can occur when pure ammonium perchlorate comes into contact with chlorine, combustible substances, metals (solid and powder), metal salts, nitrates, nitric acid, organic phosphorus, strong acids or sulphur.

TOXIC BEHAVIOUR

Ammonium perchlorate dust and solutions[36] can have an irritating effect on mucous membranes.

Ammonium perchlorate is slightly hazardous to water supplies.

WARNING. Under no circumstances should ammonium perchlorate be stored in combination with chlorate-containing compounds, due to the formation of ammonium chlorate in the presence of moisture. Nor should it be mixed with magnesium since any presence of moisture may cause spontaneous ignition if the heat build-up is sufficient.

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[36] A solution, in chemistry, is a homogenous mixture of two or more substances in relative amounts that can be varied continuously up to what is called the limit of solubility (Encyclopædia Britannica,Inc. © 2021).

POTASSIUM PERCHLORATE [$KClO_4$]

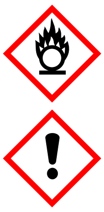

Image 49. Potassium perchlorate
(source: Bundeswehr CBRN Defence Command ©)

Potassium perchlorate has been used in pyrotechnics as the gradual replacement for potassium chlorate.

Potassium perchlorate is a colourless or white, odourless, crystalline substance. It is non-hygroscopic but partially soluble in water.

CHEMICAL BEHAVIOUR

Potassium perchlorate itself does not burn but reacts so violently with flammable substances that it can cause them to ignite, in some cases without any other ignition source. Potassium perchlorate can significantly promote an existing fire.

A violent reaction can occur when pure potassium perchlorate comes into contact with acids, combustible substances, ethanol, organic substances, powdered metals, red phosphorus or sulphur.

TOXIC BEHAVIOUR

Potassium perchlorate dust and solutions can have an irritating effect on mucous membranes.

Potassium perchlorate is slightly hazardous to water supplies.

SODIUM PERCHLORATE [$NaClO_4$]

Image 50. Sodium perchlorate
(source: Bundeswehr CBRN Defence Command ©)

Sodium perchlorate is used for medical purposes, in pyrotechnics and propellants.

Sodium perchlorate is a colourless, odourless, crystalline substance. It is hygroscopic and soluble in water and alcohol.

CHEMICAL BEHAVIOUR

Sodium perchlorate itself does not burn but reacts so violently with flammable substances that it can cause them to ignite, in some cases without any other ignition source.

An explosion or violent reaction can occur when pure sodium perchlorate comes into contact with acids, ethanol, combustible substances, powdered metals or sulphur.

TOXIC BEHAVIOUR

Sodium perchlorate dust and solutions can have an irritating effect on mucous membranes.

Sodium perchlorate should not be stored in metal or PVC containers.

Sodium perchlorate is slightly hazardous to water supplies.

4.3.4. FURTHER OXIDISERS

BARIUM CARBONATE [$BaCO_3$]

Barium carbonate is industrially used to produce glass and ceramics. It is also used as a chemical compound in bait poisons, for instance rat poison.

Barium carbonate is a colourless-white solid, which can be found as a powder or crystal. Barium carbonate is non hygroscopic. It is soluble in ethanol.

CHEMICAL BEHAVIOUR

Barium carbonate does not burn.

A violent reaction can occur when pure barium carbonate comes into contact with strong acids.

TOXIC BEHAVIOUR

Barium carbonate dust can cause irritation to mucous membranes, functional disorders in the central and peripheral nervous systems, muscle paralysis, gastrointestinal, cardiovascular and pulmonary disorders.

Barium carbonate is slightly hazardous to water supplies.

BARIUM PEROXIDE [BaO_2] OR BARIUM SUPEROXIDE

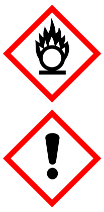

Image 51. Barium peroxide
(source: Bundeswehr CBRN Defence Command ©)

Barium peroxide has two principal applications: as an industrial decolourant or to provide a green flame colour in pyrotechnics.

Barium peroxide is a white, very slightly soluble powder. If the substance is greatly heated, it decomposes to barium oxide. It can be used as both oxidiser and fuel.

CHEMICAL BEHAVIOUR

Barium peroxide itself does not burn but increases the fire hazard when in contact with combustible materials. Barium peroxide may significantly promote an existing fire. There is an explosion hazard when barium peroxide is mixed with flammable substances.

An explosion or violent reaction can occur when pure barium peroxide comes into contact with carbon dioxide, organic substances or powdered metals (aluminium, magnesium). Barium peroxide can cause dust explosions.[37]

TOXIC BEHAVIOUR

Barium peroxide is an irritant to skin and mucous membranes. It can cause gastro-intestinal disorders, muscle and cardiovascular disorders.

Barium peroxide is slightly hazardous to water supplies.

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[37] See sub-section 4.4.2. *Solid fuels*.

CALCIUM HYPOCHLORITE $[Ca(ClO)_2]$ OR C8

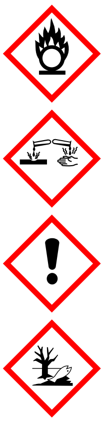

Image 52. Calcium hypochlorite
(source: Bundeswehr CBRN Defence Command ©)

Calcium hypochlorite is used industrially as a bleaching agent, such as in fabrics and paper production. It is also used as a disinfectant for swimming pools. In combination with other substances, it is used for the decontamination of chemical and biological agents.

Calcium hypochlorite is a white, crystalline substance with a strong chlorine odour. It can be found as powder or flat plates / tablets. It is soluble in water.

CHEMICAL BEHAVIOUR

Calcium hypochlorite will decompose when exposed to heat, releasing toxic gases. Calcium hypochlorite itself does not burn but increases fire hazard when in contact with combustible materials. Calcium hypochlorite can significantly promote an existing fire.

An explosion or violent reaction can occur when pure calcium hypochlorite comes into contact with acids, alkali metals, ammonium, nitromethane, organic substances, sulphur, urea or water.

TOXIC BEHAVIOUR

Calcium hypochlorite can cause irritation and has a strong corrosive effect on the eyes, respiratory tract and skin.

Calcium hypochlorite is highly hazardous to water supplies. The leakage of even small quantities into water, sewerage systems or soil must be prevented.

IRON (III) OXIDE [Fe_2O_3] OR OCHRE

This chemical does not meet the threshold criteria for GHS classification. However, chemical and toxicology information is available via data sheets on the internet.

Image 53. Iron (III) oxide
(source: Bundeswehr CBRN Defence Command ©)

Iron (III) oxide is used as polish for glass and steel, as a colour pigment, on magnetic tapes and in thermite.

Iron (III) oxide is a red-brown, odourless, crystalline powder. Larger crystals are grey-black. It does not dissolve in water and does not burn.

CHEMICAL BEHAVIOUR

An explosion or violent reaction can occur when pure iron (III) oxide comes into contact with hydrogen peroxide, magnesium, powdered aluminium or sodium nitrate.

TOXIC BEHAVIOUR

Iron (III) oxide dust can cause irritation of mucous membranes and the eyes. If orally ingested, it can cause damage to the gastrointestinal tract, liver and cardiovascular system.

Iron (III) oxide is no hazard to water supplies.

POTASSIUM CARBONATE [K_2CO_3] OR POTASH

Image 54. Potassium carbonate
(source: Bundeswehr CBRN Defence Command ©)

Potassium carbonate has a wide variety of uses, for instance in the production of potash glassware, soaps, photographic development, as a leavening agent for baked goods (e.g. gingerbread), as a cleaning agent and to neutralise acids.

Potassium carbonate is a transparent-white powder with no odour. It is hygroscopic, dissolves easily in water and does not burn.

CHEMICAL BEHAVIOUR

An explosive reaction can occur when pure potassium carbonate comes into contact with carbon or powdered calcium.

TOXIC BEHAVIOUR

Potassium carbonate can cause irritation to the eyes, skin and respiratory tract. In an aqueous solution, it becomes strongly alkaline and will cause chemical burns.

Potassium carbonate is slightly hazardous to water supplies.

POTASSIUM PERMANGANATE [$KMnO_4$]

Image 55. Potassium permanganate
(source: Bundeswehr CBRN Defence Command ©)

Potassium permanganate has a wide variety of uses in disinfectants, bleaching agents, the production of saccharin, but also in illegal drug production as it is used to process cocaine. It is listed as an essential medicine by the World Health Organization.

Potassium permanganate is a red-deep purple, crystalline substance with no odour. It dissolves in water, dyeing it purple. Solid crystalline potassium permanganate is more sensitive than its diluted solutions.

CHEMICAL BEHAVIOUR

Potassium permanganate itself does not burn but increases fire hazard when in contact with combustible materials. Potassium permanganate can significantly promote an existing fire.

An explosion or violent reaction can occur when pure potassium permanganate comes into contact with ethanol, ammonium, ammonium nitrate, ammonium perchlorate, combustible substances, concentrated acids, glycerine, hydrochloric acid, hydrogen peroxide, organic substances, phosphorus, sulphur or sulphuric acid.

TOXIC BEHAVIOUR

Potassium permanganate can cause irritation and corrosive effects to mucous membranes. It can cause serious eye damage, leading to corneal opacity.

Potassium permanganate should not be stored in containers made of copper, zinc or brass. Plastics must be tested regarding their resistance to inadvertent reactions, given that some plastics self-ignite when in contact with potassium permanganate.

Potassium permanganate is highly hazardous to water supplies. Leakage of even small quantities into water, sewerage systems or soil must be prevented.

SODIUM SULPHATE [Na_2SO_4]

Image 56. Sodium sulphate
(source: Bundeswehr CBRN Defence Command ©)

Sodium sulphate is used to produce glass, sodium silicate or liquid glass, cellulose and pharmaceutical preparations. It is also used in dyeing works to drive the dye into fibre, in washing and rinsing agents.

Sodium sulphate is an odourless, white, crystalline (or powdered) substance. It is hygroscopic and moderately soluble in water and glycerine.

CHEMICAL BEHAVIOUR

Sodium sulphate does not burn.

TOXIC BEHAVIOUR

Sodium sulphate dust and solutions can have an irritating effect on skin and eyes. If aluminium is melted together with sodium or potassium sulphate, a violent reaction or explosion may occur.

Sodium sulphate is slightly hazardous to water supplies.

4.4. FUELS

This sub-section provides an overview of fuels commonly used to manufacture HMEs, and describes their mode of action. Fuels can be solid, liquid or gaseous. Typical fuels found in HMEs contain carbon, hydrogen, nitrogen or chemical compounds including one or more of these chemicals. In addition, inorganic substances and metals are used as fuels as well. Metal fuels are solids but are listed separately in this sub-section due to their specific properties.

CHEMICAL BEHAVIOUR OF FUELS:

- Can be flammable;
- Can significantly increase / promote an existing fire;
- Can increase the risk of fire when in contact with oxidisers, strong acids and metals; and / or
- Can react so violently with oxidisers, strong acids and metals, that they ignite, sometimes without the need for an additional ignition source.

WARNING. Fuel vapours can create an explosive mixture with the surrounding air if heated above their flashpoint. Vapours can be toxic.

WARNING. Some fuels generate vapours that are (slightly) heavier than air and do not disperse in the surrounding atmosphere. Staying grounded, these vapours may travel some distance. If accidentally ignited, they can deflagrate by burning with the surrounding oxygen. Petrol is an example of a fuel with such properties.

FUNCTION OF FUELS (SOLID, LIQUID, GASEOUS) IN DEFLAGRATION AND DETONATION:

When a suitable external stimulus is applied, an oxidiser starts to decompose. It splits up at the molecular level and releases its oxygen in a gaseous state. In this dissociation process, energy is also liberated, in the form of heat. The liberation of gaseous oxygen increases pressure within the decomposition reaction, accelerating it and, therefore, leading to greater gas generation per unit of time. As a result, pressure and heat generation increase continuously. This effect promotes further decomposition.

Under the influence of heat, the gaseous oxygen reacts (oxidises) with the fuel and an oxidation-reduction reaction ensues. With the generation of further heat, the oxidation process forms further gaseous chemical substances with the fuel, such as carbon dioxide CO_2 (reaction: carbon and oxygen), sulphur dioxide SO_2 (reaction: sulphur and oxygen) and carbon monoxide CO (reaction: carbon and oxygen). The formation of each of these gases releases additional energy and increases the pressure of the reaction further, until the available oxygen is used up.

EXAMPLE: THERMAL EXPANSION

When an explosive detonates, the volume of gas (gas yield) produced provides information about the amount of work that an explosive can perform on its surroundings, such as lift, heave or shatter. To define an explosive's brisance, the gas yield is one of the main parameters, together with the heat of explosion, detonation velocity and loading density.

Under standard temperature and pressure, one mole[38] of gas produced will occupy the same volume, regardless of its chemical formula. For example, one mole of RDX will produce 3 moles of carbon monoxide (CO), 3 moles of water (H_2O) and 3 moles of nitrogen (N_2), equating to 9 moles of gas. These 9 moles of gas correspond to 908 litres (l) of gas per kg of RDX. This gas yield will undergo expansion in milliseconds, expanded and accelerated by the influence of the other parameters (such as heat of explosion) ensuring an explosive's destructive work.

Amount of gas produced per 1 kg for various explosives:

1 kg of RDX generates 908 l of gas
1 kg of TNT generates 740 l of gas[39]
1 kg of ammonium nitrate generates 980 l of gas[40]
1 kg of HMTD generates 1097 l of gas[41]
1 kg of ammonium nitrate–icing sugar generates 1001 l of gas[42]
1 kg of lead azide generates 231 l of gas[43]

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[38] One mole of a chemical compound corresponds to its relative molecular weight in grammes (g). 1 mole of a chemical compound contains about 6.022 x 10^{23} of its atoms / molecules. 1 mole of hydrogen H_2 = 2 g hydrogen H_2, 1 mole of chloride Cl_2 = 71 g chloride Cl_2, 1 mole of ammonium nitrate NH_4NO_3 = 80 gr ammonium nitrate NH_4NO_3.

[39] Rudolf Meyer, Josef Köhler and Axel Homburg, *Explosives*. Sixth Edition. (Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA, 2007).

[40] Meyer et al., *Explosives*.

[41] M.A. Ilyushin, I.V. Tselinskii and A.M. Sudarikov, *Development of components for high-energy compositions.* (SPB: LGU im. A. S. Pushkina – SPBGTI(TU), Saint Petersburg, 2006).

[42] G.P. Collett, *Home-Made Explosives, A Comprehensive Guide* (UK Ministry of Defence, 2020).

[43] J.N. Danilov, M.A. Ilyushin and I.V. Tselinskii *Industrial Explosives Part 1. Initiating explosives* (Saint-Petersburg State Institute of Technology, Saint-Peterburg, 2001).

4.4.1. LIQUID FUELS

Liquid fuels can cause fuel-air explosions. A fuel-air explosion differs from one created by a conventional explosive in that the fuel elements do not carry their own oxygen. For a fuel-air explosion to occur, fuel vapour must be mixed with ambient atmospheric air and when mixing is complete, be initiated by an ignition source. Each type of fuel has a specific lower explosive limit (the minimum ratio of fuel vapour to air below which ignition will not occur – LEL) and an upper explosive limit (the maximum ratio of fuel vapour to air above which ignition will not occur – UEL). For example: nitrobenzene has an LEL of 2% and a UEL of 9%; nitromethane has a 7.3% LEL and 22.2% UEL; hexane a 1.2% LEL and 7.4% UEL (similar to gasoline vapour); and ethylene diamine a 4.2% LEL and a 14.4% UEL.

WARNING. Caution must be applied when dealing with combustible liquid fuels. Combustible liquid fuels can cause fuel-air explosions either by themselves or when they are part of an HME that has been manufactured or stored in a condition where its vapours can mix with the air.

NOTE. A fuel-air explosion can generate sufficient detonation pressure to initiate other explosive compositions in close proximity. This is particularly important when considering fuel-air explosions that may occur in the presence of HME compositions.

AMMONIA [NH_3] OR AZANE, SPIRIT OF HARTSHORN

Image 57. 30% ammonia
(source: Bundeswehr CBRN Defence Command ©)

Ammonia is used as a synthesiser for industrially produced nitrogen-containing products such as fertilisers, explosives and dyes. When pure, it is also used in fertiliser products and cooling aggregates.

Ammonia is a colourless gas which liquefies easily under pressure. It has a pungent, suffocating odour, similar to stale urine. Ammonia dissolves in water and ethanol.

TOXIC BEHAVIOUR

Ammonia can have a strongly irritating / corrosive effect on the eyes, respiratory tract and skin. Contact with the substance may cause severe damage to the eyes, skin and respiratory tract.

Ammonia is highly hazardous to water supplies, even in small quantities. Leakage into water, sewerage systems or soil must be prevented. Under atmospheric pressure, artificially liquified ammonia will turn gaseous again.

ANILINE [$C_6H_5NH_2$] OR AMINO BENZENE

Image 58. Aniline
(source: Bundeswehr CBRN Defence Command ©)

Aniline is used in the chemical industry and for creating liquid rocket fuels. It is also used with nitromethane in mine clearance applications as liquid explosive in pipes.[44]

Aniline is a colourless, oily liquid that quickly turns brown when exposed to sunlight. It has a slightly sweet amine[45]-like (old fish-like) smell. It dissolves in water and liquid ammonia.

TOXIC BEHAVIOUR

Aniline is a serious blood and nerve toxin leading to disturbance of blood function (methaemoglobin formation) and disturbance of the central nervous system. It can irritate the eyes and mucous membranes.

Suitable fire-extinguishing agents for aniline are water (spray jet), dry extinguishing powder or carbon dioxide. Larger fires should be fought with alcohol-resistant foam or water spray.

Aniline is highly hazardous to water supplies, even in small quantities. Leakage into water, sewerage systems or soil must be prevented.

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[44] Laurence, Edgar A. Stabilized explosive containing nitromethane and amine. US Patent 3239395A filed July 18, 1945, issued March 8, 1966.

[45] Amines are explained under ethylene diamine in sub-section 4.4.1.

BENZENE [C_6H_6] OR BENZOL

Image 59. Benzene
(source: Bundeswehr CBRN Defence Command ©)

Benzene is important for the petrochemical industry. It is used in engine fuels, and products from further processing are used to produce paints, plastics, aniline, pesticides, and acetone.

Benzene is a colourless, characteristically aromatic smelling liquid which burns with a strong sooty flame. It is lighter than water and very volatile.

TOXIC BEHAVIOUR

Benzene is carcinogenic and its vapours are toxic. It has a slightly irritant effect on mucous membranes and skin and can lead to central nervous system disorders.

Benzene can be stored in glass or stainless steel. The resistance of plastics must be checked before use.

Suitable extinguishing agents are dry powder, carbon dioxide or alcohol-resistant foam.

Benzene is highly hazardous to water supplies, even in small quantities. Leakage into water, sewerage systems or soil must be prevented.

BRAKE FLUID

Image 60. Brake fluid
(source: Bundeswehr CBRN Defence Command ©)

Brake fluid is a hydraulic fluid used for braking systems in vehicles. Common brake fluids used as fuel are compositions of polyglycol compounds. Amongst other things, polyglycols are used as cooling and antifreeze agents.

Brake fluid is a viscous, odourless, colourless-yellow liquid. It is hygroscopic and dissolves in water. Colour can be added by the manufacturer.

TOXIC BEHAVIOUR

If absorbed, brake fluid is toxic and irritates skin and eyes.

Suitable extinguishing agents are water (spray jet), dry powder, carbon dioxide or alcohol-resistant foam.

Brake fluid is hazardous to water supplies.

ETHANOL [C_2H_5OH] OR ETHYL ALCOHOL

Image 61. Ethanol
(source: Bundeswehr CBRN Defence Command ©)

Ethanol of agricultural origin is produced for human consumption. Artificially derived ethanol is used for detergents, paints, cosmetics or biofuels.

Ethanol is a colourless liquid with a weak, sweet, wine-like odour. Pure or concentrated ethanol has a burning taste. It is hygroscopic and soluble in water. Ethanol is highly volatile.

TOXIC BEHAVIOUR

Ethanol has a mildly irritating effect on mucous membranes and skin. It can lead to neurotoxic problems, cardiovascular disorders, metabolic changes and kidney damage.

Suitable extinguishing agents are water (spray jet), dry powder, carbon dioxide or alcohol-resistant foam.

Ethanol is slightly hazardous to water supplies.

ETHYLENE DIAMINE [$C_2H_8N_2$]

Image 62. Ethylene diamine
(source: Bundeswehr CBRN Defence Command ©)

Heavy duty hardeners are used in two-part epoxy resin glue. Hardeners are made of amines, organic compounds and derivatives of ammonia. Ethylene diamine is a commonly used component.

Ethylene diamine is a colourless liquid with an odour of ammonia. It is hygroscopic and dissolves in water. It is moderately volatile. Aqueous solutions, that is to say ethylene diamine mixed with water, are caustic.

TOXIC BEHAVIOUR

Ethylene diamine can cause serious irritation and have a corrosive effect on skin, mucous membranes and respiratory tract.

Ethylene diamine should not be stored in containers made of aluminium or copper, magnesium zinc and their alloys.

Suitable extinguishing agents are water (spray jet), dry powder, carbon dioxide or alcohol-resistant foam.

Ethylene diamine is slightly hazardous to water supplies.

FUEL OIL [75 % $C_{10}H_{20}$ - $C_{15}H_{28}$ AND 25% AROMATIC HYDROCARBONS] SUCH AS HEATING OIL, DIESEL

Image 63. Fuel oil
(source: Bundeswehr CBRN Defence Command ©)

Fuel oil is a mixture of various hydrocarbons, with a boiling point of between 230°C and 350°C. It is used in different mixtures for heating systems and diesel engines.

Fuel oil is a colourless-yellow, oily, viscous liquid with the characteristic odour of hydrocarbons. It is lighter than water and does not dissolve in it. The addition of components with a lower boiling point can significantly reduce the flashpoint of the mixture. Heated fuel oil can ignite without an external ignition source.

TOXIC BEHAVIOUR

Fuel oil can have a severe drying and irritating effect on skin. It causes lung damage through inhalation of higher concentrated aerosols and can cause central nervous system problems.

Suitable extinguishing agents are dry powder, carbon dioxide or sand. Larger fires should be fought with foam or water spray jets.

Fuel oil is highly hazardous to water supplies even in small quantities. Leakage into water, sewerage systems or soil must be prevented.

GLYCERINE [$C_3H_8O_3$] OR GLYCEROL, GLYCYL ALCOHOL, GLYCOL

This chemical does not meet the threshold criteria for GHS classification. However, chemical and toxicology information is available via data sheets on the internet.

Image 64. Glycerine
(source: Bundeswehr CBRN Defence Command ©)

Glycerine is used to produce explosives like nitroglycerine (NG), synthetic resins and as an intermediate product for pharmaceutical products. It is used in skin care products like soaps, as well as antifreeze, hydraulic fluids and plasticisers.

Glycerine is a viscous, colourless and odourless liquid. It is hygroscopic and soluble in water and ethanol. It has a slightly sweet taste.

TOXIC BEHAVIOUR

Glycerine can cause skin and eye irritation.

Suitable extinguishing agents are water (spray jet), dry powder, carbon dioxide or alcohol-resistant foam.

Glycerine is slightly hazardous to water supplies.

HEXANE [C_6H_{14}] OR ESANI, SKELLYSOLVE B

Image 65. Hexane
(source: Bundeswehr CBRN Defence Command ©)

Hexane is used as a solvent and thinner for fast-drying paints, printing inks and adhesives.

Hexane is a colourless, volatile liquid that is easily ignitable and smells like petrol. Hexane does not dissolve in water and is lighter than water.

TOXIC BEHAVIOUR

Hexane can have an irritating effect on the eyes and upper respiratory tract. It can lead to severe drying and irritation of skin, as well as to central nervous system disorders.

Suitable extinguishing agents are dry powder or carbon dioxide.

Hexane is highly hazardous to water supplies, even in small quantities. Leakage into water, sewerage systems or soil must be prevented.

JET FUEL OR JET A-1, TS-1, JP-1, JP-5, JP-9, JP-10, COLLOQUIAL: KEROSENE

Image 66. Jet fuel
(source: Bundeswehr CBRN Defence Command ©)

Jet fuels are petroleum products mainly used in diesel fuels and aircraft engines. They are a mixture of various hydrocarbons such as alkanes, cycloalkanes, aromatics and olefins.

Kerosene is a colourless-yellowish, oily liquid with a typical petroleum-like odour. It does not dissolve in water and it is lighter than water.

TOXIC BEHAVIOUR

Kerosene can cause a severe drying and irritating effect on skin and eyes. Inhalation of highly concentrated aerosols can cause lung damage.

Suitable extinguishing agents are water (spray jet), dry powder, carbon dioxide or foam.

Kerosene is significantly hazardous to water supplies.

METHYL ETHYL KETONE (MEK) $[C_4H_8O]$ OR BUTANONE

Image 67. Butanone
(source: Bundeswehr CBRN Defence Command ©)

Butanone is used as a solvent for paints and resins (such as fibreglass), as a degreasing agent, and as a sterilising agent for medical instruments.

Butanone is a colourless, extremely flammable liquid with an acetone-like smell. It easily dissolves in water, is very volatile and evaporates quickly.

TOXIC BEHAVIOUR

Butanone can cause irritation to skin, eyes, respiratory tract and the central nervous system (drowsiness and dizziness).

Suitable extinguishing agents are water (spray jet), dry powder, carbon dioxide or alcohol-resistant foam.

Butanone is slightly hazardous to water supplies.

NITROBENZENE $[C_6H_5NO_2]$ OR NITRO BENZOL, BENZENE, OIL OF MIRBANE

Image 68. Nitrobenzene
(source: Bundeswehr CBRN Defence Command ©)

Nitrobenzene is used by the chemical industry when producing various chemicals, such as aniline or trinitrobenzene. It is used in solvents, as an additive in lubricating oils and explosives, and was used as cheap perfume for curd soaps.

Nitrobenzene is a colourless-yellow, sweet-tasting flammable liquid that smells slightly of bitter almonds or marzipan. It is heavier than water and hardly soluble in water.

TOXIC BEHAVIOUR

Nitrobenzene can cause a disturbance of blood function (methaemoglobin formation) and of the central nervous system, which is followed by blood and liver damage.

Suitable extinguishing agents are dry powder or carbon dioxide.

Nitrobenzene is highly hazardous to water supplies, even in small quantities. Leakage into water, sewerage systems or soil must be prevented.

NITROMETHANE [CH_3NO_2]

Image 69. Nitromethane
(source: Bundeswehr CBRN Defence Command ©)

Nitromethane is used in the production of rocket fuels, explosives, insecticides and as an additive for petrol. In the private sector, nitromethane is mostly used as a fuel for combustion engines in model making. Nitromethane is sold in different qualities and concentrations. Hobby-grade nitromethane used as model engine fuel has a concentration of less than 40% and is mixed with other agents such as oil, lubricants, dyes and methanol. Racing fuel-grade nitromethane is generally close to 100%. It is desensitised with methanol to prevent engine detonation.

Nitromethane is a colourless, oily liquid with an aromatic, fruity smell. It is hygroscopic, easily soluble in water and very volatile.

TOXIC BEHAVIOUR

Nitromethane can cause slight irritations of skin and mucous membranes. Higher concentrations can lead to irritations of the respiratory tract and to central nervous system problems.

Containers made of plastic must be tested to check their resistance prior to use.

Suitable extinguishing agents are water (spray jet), alcohol-resistant foam, dry extinguishing powder and carbon dioxide.

Nitromethane is significantly hazardous to water supplies.

PETROLEUM JELLY [PRIMARY $C_{15}H_{15}N$] OR VASELINE® (UNILEVER BRAND NAME)

This chemical does not meet the threshold criteria for GHS classification. However, chemical and toxicology information is available via data sheets on the internet.

Image 70. Petroleum jelly
(source: Bundeswehr CBRN Defence Command ©)

Vaseline is used in many applications, such as skin ointments, shoe polish, lubricants and leather grease.

Vaseline is a white-light yellow, soft, transparent, ointment-like mixture of aliphatic (non- aromatic) hydrocarbons. It is odourless and tasteless. It does not dissolve in water.

TOXIC BEHAVIOUR

No significant effect.

Vaseline is not hazardous to water supplies.

4.4.2. SOLID FUELS

Solid fuels can generate fine, dispersed dust. Some organic dusts and a variety of metal dusts are flammable and explosive. Deposited dust usually tends to burn, glimmer or smoulder after ignition. Dust suspended and mixed with oxygen in the air can react explosively above a given level of concentration which is known as the lower explosive limit. In general, contact or inhalation of such dust or powders may cause irritation to the eyes, nose, throat and lungs.

NOTE. A dust explosion is the explosion of a suspended mass of very fine combustible dust particles mixed with ambient atmospheric air, which can be triggered by sparks, electrostatic discharge or flames. Such triggers will cause almost any finely powdered organic material to ignite below 500°C.[46] The substance must be in a very finely dispersed form (powder, dust) and be stirred up in the air in sufficient quantities. A sudden explosion can occur because of the high amount of atmospheric oxygen that can react with the large area of surface of the dust particles.

WARNING. As storage and manufacturing areas of HMEs are not subject to safety regulations, MA organisations encountering such infrastructures must be aware of the hazards of dust explosions.

ALUMINIUM SULPHATE [$Al_2(SO_4)_3$]

Aluminium sulphate is used for water purification, foam extinguishing agents and the stain / dye industries.

Aluminium sulphate is a colourless-white, odourless, crystalline solid. It can be found as pellets, crystals, powder or granules. Aluminium sulphate dissolves in water, is not flammable and does not cause dust explosions.

TOXIC BEHAVIOUR

Aluminium sulphate particles can have a strongly irritant effect on mucous membranes, such as in the eyes.

Aluminium sulphate is slightly hazardous to water supplies.

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[46] W.E. Baker and M.J. Tang, *Gas, Dust and Hybrid Explosions* (Elsevier Science, 1991).

AMMONIUM SULPHATE [$(NH_4)_2SO_4$]

This chemical does not meet the threshold criteria for GHS classification. However, chemical and toxicology information is available via data sheets on the internet.

Image 71. Ammonium sulphate
(source: Bundeswehr CBRN Defence Command ©)

Ammonium sulphate is a fertiliser salt produced in large quantities. It is also used in the production of foam extinguishing agents and in the stain / dye industries.

Ammonium sulphate is a colourless, odourless, crystalline solid. It can be found as pellets, crystals, powder or granules. Ammonium sulphate is slightly hygroscopic and dissolves in water. It is not flammable but will become unstable and decompose when exposed to temperatures higher than 235°C.

TOXIC BEHAVIOUR

Ammonium sulphate particles may have an irritant effect on mucous membranes, such as in the eyes. The effects, however, are not documented.

Ammonium sulphate is slightly hazardous to water supplies.

BORON [B]

This chemical does not meet the threshold criteria for GHS classification. However, chemical and toxicology information is available via data sheets on the internet. Boron is used in alloys, pyrotechnics, propellants and in applications needing high stability against physical force, such as in tennis rackets, for example.

Boron forms very hard, grey-black, shiny crystals. Amorphous boron is a brown, odourless powder. It burns in the air with a strong green flame. Boron’s reactivity increases with temperature, while its stability decreases. It does not dissolve in water.

TOXIC BEHAVIOUR

Not documented.

Suitable extinguishing agents are dry sand or metal fire extinguishers, unsuitable ones are water and foam.

Boron poses no hazard to water supplies.

CHARCOAL (UP TO 90% CARBON)

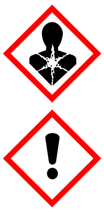

Image 72. Finely ground charcoal
(source: Bundeswehr CBRN Defence Command ©)

Charcoal is used in filters, cleaning agents, disinfectants, medical products, propellants, pyrotechnics and as fuel.

Charcoal is a black, odourless, inorganic carbon compound. It does not dissolve in water. Charcoal is flammable and can burn without creating a flame. It can contribute to dust explosions.

TOXIC BEHAVIOUR

Carbon powder and dust can have an irritating effect on mucous membranes.

Charcoal poses no hazard to water supplies.

COFFEE (SUCROSE & POLYSACCHARIDE)

This organic matter does not meet the threshold criteria for GHS classification. However, chemical and toxicology information is available via data sheets on the internet.

Image 73. Coffee
(source: Bundeswehr CBRN Defence Command ©)

Coffee is extracted from the coffee bean and is a stimulant to the central nervous system.

Ground coffee is a brown to dark brown powder with a sweet-smelling, characteristic odour. It can be used as a component for fuel. Usually, a metal fuel is added to the mixture.

TOXIC BEHAVIOUR

Coffee powders and dust can have an irritating effect on mucous membranes.

Coffee poses no hazard to water supplies.

DEXTRIN $[(C_6H_{10}O_5)_n]$[47]

This organic matter does not meet the threshold criteria for GHS classification. However, chemical and toxicology information is available via data sheets on the internet.

Image 74. Dextrin
(source: Bundeswehr CBRN Defence Command ©)

Dextrin is used in fur glues, food processing, pharmaceutical products, as a pyrotechnic stabiliser, as a binder and a fuel.

Dextrin is a white-yellowish, odourless powder carbohydrate. It is flammable, hard to ignite and dissolves in water.

TOXIC BEHAVIOUR

Not documented.

Dextrin’s potential hazard to water supplies is not documented.

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[47] Dextrin creates chains, meaning the molecules are added, because of this n = 1, 2, 3,….,n+1.

NAPHTHALENE [$C_{10}H_8$] OR CAMPHOR TAR

Image 75. Naphthalene
(source: Bundeswehr CBRN Defence Command ©)

Naphthalene is used to produce colours (dyes), fuels, solvents and pesticides (mothballs).

Naphthalene is a colourless-white, intense-smelling, crystalline, solid hydrocarbon, presenting a tar / mothball smell. Naphthalene can be found as flakes, powder, prills or balls. It does not dissolve in water but can evaporate at room temperature.

TOXIC BEHAVIOUR

Naphthalene can cause weak irritant effects on mucous membranes and skin. It can lead to central nervous system disorders and damage to red blood cells.

Suitable extinguishing agents are water (spray jet), dry extinguishing powder, foam and carbon dioxide.

Naphthalene is highly hazardous to water supplies, even in small quantities. Leakage into water, sewerage systems or soil must be prevented.

PARAFFIN [C_nH_{2n+2}] OR WAX, BABY OIL

This chemical does not meet the threshold criteria for GHS classification. However, chemical and toxicology information is available via data sheets on the internet.

Image 76. Paraffin
(source: Bundeswehr CBRN Defence Command ©)

Paraffin is used in cosmetics, pharmaceutical products, impregnation agents, propellant components and candles.

Paraffin is a white-yellowish, odourless, tasteless, waxy hydrocarbon. It can be found as powder, granules, lumps, oils, liquids. It does not dissolve in water.

TOXIC BEHAVIOUR

Under normal conditions, paraffin poses no threat to health.

Paraffin presents no hazard to water supplies.

SAWDUST

This organic matter does not meet the threshold criteria for GHS classification. However, chemical and toxicology information is available via data sheets on the internet.

Image 77. Sawdust
(source: Bundeswehr CBRN Defence Command ©)

Sawdust is used as insulation, to produce board, as fuel, and has been used as an additive in explosives.

Sawdust can be found as a fine powder, flakes or dust, whose colour and odour depend on the kind of wood used. Fine sawdust can contribute to a dust explosion.

TOXIC BEHAVIOUR

No toxic behaviour has been documented. Inhalation of dust or powder may cause irritation to the eyes, nose, throat and lungs.

No hazards to water supply are documented.

SORBITOL [$C_6H_{14}O_6$] OR GLUCITOL, D-SORBIT

This chemical does not meet the threshold criteria for GHS classification. However, chemical and toxicology information is available via data sheets on the internet.

Image 78. Bag of sorbitol (source: CAR ©)

Sorbitol is used as a food sweetener and as a carrier for humectants in food production.

Sorbitol is a sweet-tasting, odourless, transparent-whiteish solid. It is easily soluble in water and is hygroscopic. Sorbitol can contribute to a dust explosion.

TOXIC BEHAVIOUR

Under normal conditions, sorbitol poses no threat to health. In case of intolerance, sorbitol intake may cause gastrointestinal problems.

No available research has yet been conducted on sorbitol’s water-polluting effect. As a precaution, penetration into subsoil and water supplies must be prevented.

SUCROSE [$C_{12}H_{22}O_{11}$] OR SUGAR

This chemical does not meet the threshold criteria for GHS classification. However, chemical and toxicology information is available via data sheets on the internet.

Image 79. Loose sucrose crystals
(source: Bundeswehr CBRN Defence Command ©)

Image 80. Sucrose in lump form
(source: Bundeswehr CBRN Defence Command ©)

Sucrose is used as food and as a food additive, as well as in the production of alcohols, glycerines, explosives and fuels.

Image 81. Bag of sugar (sucrose) (source: CAR ©)

Sucrose is a white, crystalline carbohydrate. It is odourless with a sweet taste. Sucrose dissolves in water and ethanol. Sucrose can contribute to a dust explosion.

TOXIC BEHAVIOUR

Not documented.

In large amounts, sucrose is slightly hazardous to water supplies.

4.4.3. METALLIC FUELS

Most metals used for HMEs are self-igniting (pyrophoric) solids.

NOTE. Pyrophoric solids – finely dispersed, fine metallic powders and dust that can heat up in the air, reacting with oxygen and ignite at room temperature without external stimuli. Ignition sensitivity depends, inter alia, on particle size and distribution. The finer the particle, the larger the surface area and the greater the pyrophoricity.

As storage and manufacturing areas of HMEs are not subject to industrial hygiene standards, MA staff encountering such infrastructures must be aware of the hazard of a fuel-air explosion involving metals.

Grinders, food blenders, rock tumblers, and so forth, are used to produce the required fine particles. MA staff encountering any of these devices must be aware that opening may lead to a spontaneous reaction when the fine metal particles come into contact and mix with the inflowing atmospheric oxygen.

Contact with or inhalation of dust or powders may cause irritation to the eyes, nose, throat and lungs.

WARNING. Fine metal powders can react spontaneously and violently when exposed abruptly to atmospheric oxygen.

WARNING. The powder and dust of the metals listed may form flammable gases when they encounter water.

WARNING. Metal powder and dust are sensitive to static discharge and should not be handled without prior earthing procedures.

PURPOSE OF METALS ACTING AS FUELS IN AN ENERGETIC REACTION

Metal fuels reacting with an oxidiser in an energetic reaction produce heat (often more than 2000°C) and a solid metal oxide. For example, aluminium powder's reaction with an oxidiser will produce aluminium oxide (Al_2O_3); magnesium powder's reaction with an oxidiser will produce magnesium oxide (MgO). Unlike other fuels, metal fuels do not contribute to an increase in gas volume during an explosive decomposition but to an increase of the heat of an explosion. The added temperature contributes to a very large thermal expansion of other gaseous products. This accelerated expansion increases the pressure within the reaction. The addition of metals also leads to an increased incendiary effect.

ALUMINIUM [Al]

Image 82. Aluminium
(source: Bundeswehr CBRN Defence Command ©)

Aluminium has a wide range of uses, including in vehicle and aircraft production, in the construction industry, civil and electrical engineering, in the manufacture of everyday objects and food-safe packaging, including foils. Powdered aluminium is needed to produce metallic paints and is also used to manufacture pyrotechnics, thermites, fireworks and explosives.

Aluminium is a silvery-white, shiny, ductile, solid metal. It can be found as a solid, as a flake and as a powder. Its shine fades quickly when exposed to air, due to the formation of aluminium oxide on the surface.

CHEMICAL BEHAVIOUR

Aluminium powder can heat up at room temperature in air without added energy input and finally ignite. Its ignitability depends, among other things, particularly on particle size and degree of distribution. On contact with water, aluminium powder forms flammable gases.

Suitable extinguishing agents for aluminium powder are dry sand or fire extinguishers for metals. Unsuitable extinguishing agents are water, dry powder, foam and carbon dioxide.

No available research has yet been made regarding aluminium's water-polluting effect. Penetration into subsoil and water supplies must be prevented.

Image 83. Aluminium (partially powdered) (source: FSD ©)

Image 84. Drum of aluminium paste (source: CAR ©)

ELECTRON [Mg/Al]

Electron is the technical designation for a magnesium aluminium alloy with 86% magnesium and 14% aluminium. It is made as a solid but can be ground into powder. It was used for the construction of incendiary bombs because of its strong exothermic decomposition. Electron burns to produce temperatures of more than 2200°C, emitting a high intensity flame that can be blinding.

MAGNALIUM [Al/Mg]

Magnalium is the technical designation of an aluminium–magnesium alloy with 2%–5% magnesium and small amounts of other elements such as iron or chrome. It is used as a component of car and plane parts, metal implements and solid metal casings / frames. Powdered magnalium is also used as fuel in pyrotechnics, burning up to high temperatures (as aluminium and magnesium do on their own) and forming yellowish white sparks.

Magnalium is a greyish-white, hard alloy. It can be found as a solid or as a powder. Its strength and resistance to corrosion depend on the aluminium–magnesium ratio.

No available research has yet been made regarding magnalium’s water-polluting effects. As a precaution, penetration into subsoil and water supplies must be prevented.

MAGNESIUM [Mg]

Image 85. Magnesium
(source: Bundeswehr CBRN Defence Command ©)

Magnesium is used in the electrical and in the metal processing industries. Because of its energetic properties, it is used as a fire starter and as a component of incendiary ammunition and pyrotechnics (for flares burning in an environment lacking gaseous oxygen, such as under water, for instance). Magnesium alloys are used in products that benefit from being lightweight, such as car seats, casings or housing products such as cameras and power tools.

Magnesium is a silver-white, shiny, ductile, solid metal. It can be found as a solid, pressed and as cuttings. Magnesium burns with a very strong, UV-rich, white light.

CHEMICAL BEHAVIOUR

Magnesium powder can heat up at room temperature in air without added energy input and finally ignite. The ignitability depends, in particular, on particle size and degree of distribution. The substance forms flammable gases on contact with water.

Suitable extinguishing agents for magnesium powder are dry sand or fire extinguishers for metals. Unsuitable extinguishing agents are water, dry powder, foam and carbon dioxide.

No available research has yet been made regarding magnesium's water-polluting effects. As a precaution, penetration into subsoil and water supplies must be prevented.

SODIUM [Na]

Image 86. Sodium
(source: Bundeswehr CBRN Defence Command ©)

Metallic sodium is used to produce sodium compounds. It is strongly hygroscopic and serves as a drying agent for several applications. Sodium serves as a reducing agent in metallurgy.

Sodium is a silver-white, shiny, waxy metal that is so soft that it can be cut with a knife. Usually, it is covered with a grey-brown crust (sodium hydroxide and sodium carbonate), which protects the sodium underneath. In the air, sodium burns with a yellow flame.

CHEMICAL BEHAVIOUR

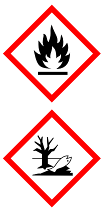
Sodium is a flammable substance but difficult to ignite. In contact with water, it forms flammable gases that may ignite spontaneously. Sodium is not volatile.

Suitable extinguishing agents are dry sand, dry cement or fire extinguishers for metals. Unsuitable extinguishing agents are water and carbon dioxide.

Sodium is slightly hazardous to water supplies.

ZINC [Zn]

Image 87. Zinc
(source: Bundeswehr CBRN Defence Command ©)



Zinc is used to increase the corrosion resistance of metals, for construction materials and day-to-day objects, in batteries and in the chemical industry. Zinc and zinc compounds are used in pyrotechnics when low combustion temperatures and an easy ignition are desired. Pyrotechnic applications of zinc and zinc compounds are hexachloroethane smokes.

Zinc is a bluish-white metal. In the air it slowly forms ‘white rust’ (zinc hydroxide carbonate), which protects the zinc underneath. It can be found as a powder. Zinc burns with a green flame.

CHEMICAL BEHAVIOUR

Zinc powder can heat up at room temperature in air without added energy input and finally ignite. The ignitability depends, in particular, on the particle size and degree of distribution. The substance forms flammable gases on contact with water.

WARNING. Humidity increases zinc dust’s potential for auto-ignition.

Suitable extinguishing agents for zinc powder are dry sand, clay, sodium hydrogen carbonate and, in exceptional cases (nothing else available), fire extinguishers for metals. Water must not be used as an extinguishing agent.

Zinc powder is highly hazardous to water supplies, even in small quantities. Leakage into water, sewerage systems or soil must be prevented.

4.5. ADDITIVES AND CATALYSTS

This sub-section presents substances and components used in the manufacturing of HME that are not acids, fuels or oxidisers or that are to be highlighted because of their significant impact on HME's sensitivity and stability.

4.5.1. SENSITISERS AND TINDER[48]

Sensitisers increase an HME's sensitivity to initiation by flame, spark, heat, shock, friction, etc.

Tinder lowers the ignition temperature of a low explosive.

Chemical sensitisers / tinder are substances or compounds which include amines, red phosphorus, sulphur, metal powders, finely ground glass or grit. A physical sensitiser, such as air voids between explosive crystals, sensitises an explosive mixture without the need for a chemical additive (referring to hotspot ignition).

In general, sensitisers and tinder may also be used as fuels.

WARNING. If an HME which could contain added sensitisers or tinder is encountered, risk mitigation and render safe procedures should be reviewed and adapted to address hazards resulting from its increased sensitivity and / or lowered ignition temperature.

PHOSPHORUS [P] – WHITE PHOSPHORUS AND RED PHOSPHORUS

Phosphorus is used to produce pesticides, fertilisers, matches, flame retardants, smoke-producing pyrotechnics and incendiary ammunition.

WHITE OR YELLOW PHOSPHORUS

Image 88. White phosphorus
(source: Bundeswehr CBRN Defence Command ©)

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[48] Tinder: very flammable substance adaptable for use as kindling.

White phosphorus is a white-yellowish, crystal solid with a consistency comparable to wax. It darkens when exposed to light. White phosphorus has a garlic-like odour (as do some phosphorus compounds) and does not dissolve in water. It emits a greenish light (visible in the dark) and white smoke when exposed to air. White phosphorus reacts violently with oxidising agents.

CHEMICAL BEHAVIOUR

White phosphorus is self-igniting on contact with air and sensitive to heat, friction and impact. White phosphorus can heat up independently and will ignite at room temperature in air without any additional energy supply. The ignition temperature in dry air is higher than in moist air (30°C). Its ignition readiness depends, among other things, on the grain size and degree of distribution. White phosphorus burns with a glowing flame.

Ignited phosphorus will not stop burning until it is either completely oxidised or isolated from oxygen in the air. It will burn skin, flesh and tissue and create deep, severe, slow-healing wounds.

TOXIC BEHAVIOUR

White phosphorus can lead to local damage of mucous membranes and skin by destroying tissue (necrosis). It can cause gastrointestinal disorders, liver damage with severe metabolic disorders and damage to heart and kidneys. The smoke of burnt white phosphorus acts as an irritant to the eyes, mucous membranes, skin and respiratory tract / lungs.

Suitable extinguishing agents are water (spray jet) and damp sand. An unsuitable extinguishing agent is carbon dioxide. If possible, burning white phosphorus should be soaked and covered with water or damp sand. Before disposal, residues may have to be subjected to chemical treatment to prevent self-reignition.

WARNING. White phosphorus cannot be permanently extinguished with water; other measures that cut it off from oxygen must be taken, otherwise it will reignite in the air as soon as the water has evaporated.

NOTE. Among possible phosphorus modifications, white phosphorus is the easiest to produce as well as the most toxic and unstable. Both modifications, red and white, will significantly increase an HME's sensitivity.

White phosphorus is highly hazardous to water supplies, even in small quantities. Leakage into water, sewerage systems or soil must be prevented.

WARNING. White or yellow phosphorus reacts in humid air by heating and forming hydrogen phosphide (phosphine) and phosphoric acid, accompanied by a garlic odour. These vapours are extremely damaging if inhaled.

RED PHOSPHORUS

Image 89. Red phosphorus
(source: Bundeswehr CBRN Defence Command ©)

Red phosphorus is a deep red-purplish powder. This artificial modification of phosphorus is flammable, odourless and does not dissolve in water.

CHEMICAL BEHAVIOUR

Red phosphorus can be easily ignited by brief exposure to an ignition source and continues to burn after removal from that source. It is considered a dangerous fire hazard. The finer the substance, the greater the risk of ignition, including the hazard of a dust explosion. Although red phosphorus is not self-igniting in air, a low energy impact, friction or electrostatic discharge can cause ignition.

TOXIC BEHAVIOUR

Red phosphorus is considered non-toxic. However, the evaporation of red phosphorus in a fuel-oxidiser mixture results in an extremely toxic vapour. Toxic fumes are also emitted when the red phosphorus is heated. The smoke of burnt red phosphorus vapour is not toxic in small amounts but can act as an irritant to the eyes, skin and respiratory tract.

Suitable extinguishers for small fires are water (spray jet), wet sand or wet fire blankets. Larger fires can be fought with water spray. Unsuitable extinguishing agents are dry extinguishing powder and carbon dioxide.

Red phosphorus is slightly hazardous to water supplies.

WARNING. Red phosphorus reacts in humid air by heating and forming hydrogen phosphide (phosphine) and phosphoric acid, accompanied by a garlic odour. These vapours are extremely damaging if inhaled.

SULPHUR [S] OR BRIMSTONE

Image 90. Sulphur
(source: Bundeswehr CBRN Defence Command ©)

Sulphur is used to produce sulphuric acid, sulphate-based fertilisers, and dyes in the pharmaceutical industry, and as a fuel in pyrotechnics and propellants.

Sulphur is a stable, yellow-pale yellow, solid substance. It can be found as powder or as brittle crystals.

CHEMICAL BEHAVIOUR

Sulphur does not dissolve in water but is soluble in benzene, aniline, tetrachloride and liquid ammonia. Sulphur as a solid is hardly flammable but, once melted, it is easy to ignite. If exposed to heat, it burns in the air with a blue flame.

> **WARNING. When mixed with HME, sulphur can lower the ignition temperature to less than 200°C, making some HME extremely susceptible to flame and, given sulphur's crystallinity, it also lowers impact sensitivity. For sensitive and less stable HMEs that are contaminated with sulphur, transport-induced friction can lead to spontaneous decomposition. Appropriate disposal methods need to be considered in case of suspected sulphur contamination.**

TOXIC BEHAVIOUR

Sulphur can cause irritation to the eyes as well as irritation and inflammatory changes to the mucous membranes of the respiratory tract.

Suitable extinguishing agents are water (spray jet), dry extinguishing powder, foam and carbon dioxide.

Sulphur is slightly hazardous to water supplies.

4.5.2. CATALYSTS, REACTANTS, BINDERS AND PHLEGMATISERS

Catalysts and reactants are used in the production of HMEs.

Catalysts are used to increase the rate of a chemical reaction and thereby cause the chemical equilibrium to be established more quickly. They are not consumed in the process.

Reactants are substances participating in the chemical reaction. A reactant will change on a molecular level. Nearly all acids act as reactants.

Binders are used to hold together and improve the homogeneity of explosive mixtures. Binders can increase the resistance to mechanical impacts, such as that experienced by propellant grains in storage and transport. A break in the propellant grain would alter the burning rate with potentially catastrophic results, so the binder minimises the chances of this occurring. Typical binders are asphalts, plastics or resins.

Phlegmatisers are used to decrease an explosive's susceptibility to friction and impact or moderate cap sensitivity and detonation velocity. They desensitise an explosive. Phlegmatisers can be waxes, which lubricate the explosive crystals and act as a binder as well.

NOTE. Phlegmatisation and dilution decrease the sensitivity and reactivity of HMEs and chemicals. Depending on the substance used (for instance acetone), flammability may increase while the ability to detonate is eliminated. Furthermore, phlegmatisation may influence a disposal method. Some methods such as phlegmatisation with water must not be considered as permanent, as phlegmatisers can evaporate; the effect may not last and a desensitised HME may regain properties similar to those it had prior to processing.

HINT. Phlegmatisers can be used to neutralise an improvised explosive's ability for initiation by decreasing its sensitivity to nearly zero.

WARNING. Both catalysts and reactants are normally neutralised in the production of military or industrial explosives. In HMEs this is not generally the case and as such their presence can increase sensitivity. In some instances, reactants such as nitric acid can lead to auto-ignition of certain HMEs over time.

ACETONE [$(CH_3)_2CO$] OR KETONE PROPANE, PROPANONE, DIMETHYL KETONE

Image 91. Acetone
(source: Bundeswehr CBRN Defence Command ©)

Acetone is a frequently used solvent, for lacquers, acetyl silk but also as nail polish remover, for example. As a gelatinising agent, it plays a role in explosives technology.

Acetone is a colourless, fruit-smelling, highly flammable and highly volatile liquid. Its flashpoint is -20°C.

CHEMICAL BEHAVIOUR

Acetone vapours form explosive mixtures with air at very low mixing concentrations. Acetone dissolves in water.

Explosions and dangerous reactions can occur if acetone comes into contact with acids (e.g. hydrogen peroxide, nitric acid), strong oxidisers and fuels (e.g. boron, sodium).

TOXIC BEHAVIOUR

Acetone can cause an irritating effect to the eyes and the upper respiratory tract. In high concentrations, it can disturb the central nervous system and has a narcotic effect.

Most plastics are not suitable for storing acetone, as it is a solvent.

Suitable extinguishing agents are water (spray jet), dry extinguishing powder and carbon dioxide. Large fires should be fought with alcohol-resistant foam or sprayed water.

Acetone is slightly hazardous to water supplies.

CARBON TETRACHLORIDE [CCl_4] OR TETRACHLORMETHANE, BENZIFORM, TETRAFORM

Image 92. Carbon tetrachloride
(source: Bundeswehr CBRN Defence Command ©)

Carbon tetrachloride is hardly used nowadays because of its toxicity and its impact on the environment. It was used in refrigerators, metal degreasing, as a grain fumigant, in pesticides, as an agent for fire extinguishers and as a dry cleaner for textiles. It is used in improvised carbon tetrachloride explosives and in improvised smoke-generating pyrotechnics.

Carbon tetrachloride is a colourless liquid with an unpleasant sweet stench. It is volatile and does not dissolve in water. Carbon tetrachloride has a degreasing effect and acts as a solvent.

CHEMICAL BEHAVIOUR

Carbon tetrachloride is not flammable but can promote fires and explosions when mixed with other fuels and other reactants. Explosions and dangerous reactions can occur if carbon tetrachloride comes into contact with alkali metals, strong oxidisers or powdered metals.

TOXIC BEHAVIOUR

Carbon tetrachloride can cause a weak to moderate irritant effect on skin and mucous membranes, severe damage to liver and kidneys, as well as central nervous system and gastrointestinal disorders. Inhalation of its fumes can be lethal.

Unsuitable storage containers are made of aluminium, copper, zinc and their alloys, iron and rubber. Suitable containers are made from stainless steel, polytetrafluoroethylene (PTFE / Teflon™)[49] or fluorinated rubber.

Carbon tetrachloride is highly hazardous to water supplies even in small quantities. Leakage into water, sewerage systems or soil must be prevented.

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[49] Teflon™ is the trade name for PTFE used by DuPont de Nemours, Inc. Teflon™ is a fairly inert chemical. It is a white, non-combustible, odourless solid that does not dissolve in water. Explosions and dangerous reactions can occur if PTFE / Teflon™ comes into contact with powdered aluminium, alkali metals, flour or strong oxidisers.

COPPER (II) SULPHATE [$CuSO_4$] OR CUPRIC SULPHATE

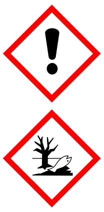

Image 93. Copper sulphate. The dry white powdered copper sulphate becomes blue when in contact with water

Copper sulphate is used in disinfection agents against algae, to produce paints and drying agents and in pyrotechnics, as it burns with a blue-greenish colour.

Copper sulphate is a white-greyish, odourless powder. It easily dissolves in water and is hygroscopic.

CHEMICAL BEHAVIOUR

Copper sulphate is non-flammable and does not produce a dust explosion.

Explosions or dangerous reactions can occur if copper sulphate comes into contact with acetylene, potassium chlorate, powdered magnesium or strong lyes (metal hydroxides).

TOXIC BEHAVIOUR

Copper sulphate can have an irritant to damaging effect on mucous membranes and skin. If ingested it can cause severe gastrointestinal and circulatory disturbances, blood count changes and functional changes leading to kidney and liver damage.

Copper sulphate is highly hazardous to water supplies even in small quantities. Leakage into water, sewerage systems or soil must be prevented.

COTTON [$C_6H_{10}O_5$]

This organic matter does not meet the threshold criteria for GHS classification. However, chemical and toxicology information is available via data sheets on the internet.

Image 94. Cotton
(source: Bundeswehr CBRN Defence Command ©)

The main use for cotton is in the textile industry; however, when treated with nitric acid, pure cotton is used to produce explosives and propellants, especially nitrocellulose and cellulose acetate.

Cotton is a bunch of soft, stretchy, organic fibres. Its colour depends on the species and processing of the harvested fibre. Cotton is not soluble in water.

CHEMICAL BEHAVIOUR

Cotton is flammable. Cotton dust can cause dust explosions.

TOXIC BEHAVIOUR

No particular toxic behaviour is known.

No hazards to water supplies are documented.

ERYTHRITOL [$C_4H_{10}O_4$] OR PHYCITOL, PHYCITE, (VARIETY OF TRADE NAMES)

Image 95. Erythritol
(source: Bundeswehr CBRN Defence Command ©)

Erythritol is a four-carbon sugar that is found in algae, fungi and lichens. It is twice as sweet as sucrose and can be used as a coronary vasodilator. It is used as a sugar substitute and precursor for the military explosives erythritol tetranitrate (ETN) and PETN.

It is a colourless-white, sweet-tasting, odourless, crystalline sugar alcohol.

Image 96. Bag of erythritol
(source: Kräuterhaus Sanct Bernhard ©)

CHEMICAL BEHAVIOUR

Erythritol is flammable, hard to ignite and dissolves in water.

TOXIC BEHAVIOUR

Powder and dust can have an irritating effect on mucous membranes.

Erythritol’s impact on water supplies is not documented.

ETHYLENE GLYCOL [$C_2H_6O_2$] OR GLYCOL ALCOHOL, ANTIFREEZE

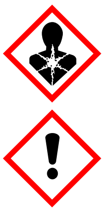

Image 97. Ethylene glycol
(source: Bundeswehr CBRN Defence Command ©)

Ethylene glycol is used as an antifreeze agent for engine cooling water, as a de-icing agent, as a plasticiser in the plastics industry and to produce explosives. It can be a component of hydraulic brake fluid as well.

Ethylene glycol is a colourless, nearly odourless, viscous liquid which is miscible with water. It is hygroscopic and not very volatile. Colour can be added by manufacturers.

CHEMICAL BEHAVIOUR

Dangerous reactions can occur if ethylene glycol comes into contact with fuming nitric acid, potassium permanganate, strong oxidisers or sulphuric acid.

TOXIC BEHAVIOUR

Ethylene glycol can cause minor irritations to mucous membranes and skin. It has a neurotoxic effect and causes cardiovascular disturbances, metabolic changes and kidney damage.

Suitable materials for containers are glass, stainless steel, PE, PTFE, PP and natural rubbers. Plastics must be checked for their resistance before use.

Suitable extinguishing agents are water (spray jet), dry extinguishing powder and carbon dioxide. Larger fires should be fought with alcohol-resistant foam or sprayed water.

Ethylene glycol is hazardous to water supplies.

FORMALDEHYDE [CH_2O] OR METHANAL

Image 98. Formaldehyde
(source: Bundeswehr CBRN Defence Command ©)

Formaldehyde is used to preserve biological preparations and to produce plastics or disinfectants.

Formaldehyde is an almost colourless liquid or gas with a pungent and suffocating odour. It is easily soluble in water.

CHEMICAL BEHAVIOUR

In both gas and liquid form, formaldehyde is extremely flammable and can form explosive mixtures with air.

Explosions and dangerous reactions can occur if formaldehyde comes into contact with hydrochloric acid, hydrogen peroxide, magnesium carbonate, nitric acid, phenol, potassium permanganate, sodium hydroxide or strong oxidisers.

TOXIC BEHAVIOUR

Formaldehyde is very toxic. It can cause an irritating to corrosive effect on the eyes and skin and can cause a skin sensitising effect (dermatitis, allergic reactions, pustular eruptions, etc.). Formaldehyde can lead to irritation of the respiratory tract.

Suitable materials for containers are aluminium, glass, stainless steel or PE.

Suitable extinguishing agents are water (spray jet), dry extinguishing powder and carbon dioxide. Larger fires should be fought with alcohol-resistant foam or sprayed water.

Formaldehyde is highly hazardous to water supplies, even in small quantities. Leakage into water, sewerage systems or soil must be prevented.

HEXACHLOROETHANE [C_2Cl_6] OR PERCHLORETHANE, CARBON HEXACHLORIDE

Image 99. Hexachloroethane
(source: Bundeswehr CBRN Defence Command ©)

Hexachloroethane is used in the smelting of non-ferrous metals and to produce high-pressure lubricants. For military applications, it is used in pyrotechnics and as a filling for smoke grenades.

Hexachloroethane is a colourless-white, crystalline powder with a camphor-like odour (strong, fragrant, aromatic-woody, eucalyptus-scented).

CHEMICAL BEHAVIOUR

Hexachloroethane is not flammable and is insoluble in water. It passes into a gas phase without melting and evaporates when exposed to air. Hexachloroethane emits toxic fumes when heated to decomposition.

TOXIC BEHAVIOUR

Hexachloroethane causes irritant effects on mucous membranes and slight irritation to skin. It may cause respiratory damage as well. In high concentrations it causes central nervous system disturbances.

Hexachloroethane is highly hazardous to water supplies, even in small quantities. Leakage into water, sewerage systems or soil must be prevented.

HEXAMINE [$C_6H_{12}N_4$] OR ESBIT,[50] FUEL TABLETS, HEXAMETHYLENETETRAMINE, UROTROPINE

Image 100. Hexamine
(source: Bundeswehr CBRN Defence Command ©)

Image 101. Hexamine pressed as an ESBIT block
(source: Bundeswehr CBRN Defence Command ©)

Hexamine is used to produce amino- and phenol-based plastics, as a food preservative and as pressed dry fuel tablets. Hexamine is a white, crystalline powder with a sea-fish[51] odour. It can be found as a powder or tablet.

CHEMICAL BEHAVIOUR

Hexamine is flammable and can be easily ignited by brief exposure to a source of ignition and continues to burn after removal from the source. The finer the hexamine is distributed, the greater the risk of ignition. It can cause dust explosions. Hexamine easily dissolves in water, is hygroscopic and sensitive to moisture.

An explosion or violent reaction can occur when hexamine comes into contact with acids (e.g. nitric acid), peroxides or oxidisers.

Suitable extinguishing agents are water (spray jet), dry extinguishing powder, foam and carbon dioxide.

Hexamine is moderately dangerous for water supplies.

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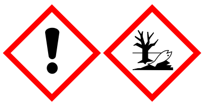
[50] ESBIT is the abbreviation of ‘Erich Schumms Brennstoff in Tablettenform’, a former trademark.

[51] Amines are descendants of ammonia; they give old(er) fish their characteristic smell. Because of amines, burnt dry fuel like ESBIT smells fishy.

HYDRAZINECARBOXIMIDAMIDE [CH_6N_4] OR AMINOGUANIDINE, PIMAGEDINE, GUANYL HYDRAZINE



Aminoguanidine is used to produce pharmaceutical products and is used in animal husbandry to protect boar spermatozoa against the deleterious effects of oxidative stress. It is used in lotions, shampoos, soaps and toothpastes. Finding pure aminoguanidine can be an indicator of the production of tetrazene. Aminoguanidine nitrates are used for propellants.

Aminoguanidine is a colourless-white, odourless crystalline solid.

CHEMICAL BEHAVIOUR

Aminoguanidine is soluble in water. This substance is flammable but difficult to ignite.

TOXIC BEHAVIOUR

Aminoguanidine causes irritation to mucous membranes and slight irritation to skin. It may cause respiratory damage as well.

Aminoguanidine is moderately dangerous for water supplies.

IODINE [I_2]

Image 102. Iodine
(source: Bundeswehr CBRN Defence Command ©)

Iodine is used for medical applications, such as disinfectants. It can be encountered in the production of improvised primary explosives.

Iodine consists of grey-black, shiny metallic, pungent-smelling, flake-like crystals that gradually evaporate in the air. When rapidly heated, iodine sublimates to form a vile vapour. It is not flammable. Iodine is sparingly soluble in water. It dissolves readily in ethanol to form a brown colour and in benzene to form a red colour.

CHEMICAL BEHAVIOUR

Iodine is considered to be very aggressive in terms of corrosive power; it even decomposes cork and natural rubber. An explosion or violent reaction can occur if it comes into contact with alkali metals, ammonia, ammonia compounds, potassium in combination with shock, potassium iodide, copper tetra amine sulphate, mercury oxide and ethanol / methanol, silver azide, fluorine, combustibles, phosphorus, wet aluminium powder, aluminium powder-ether mixtures, petrol, boron in combination with heat, iron powder, formaldehyde, potassium in combination with heat, lithium, magnesium (powder, wet), metal acetylides / carbides, sulphur, turpentine and wet zinc powder.

TOXIC BEHAVIOUR

Iodine vapour can cause irritating to corrosive effects to the eyes and skin and severe irritation of the respiratory tract (risk of lung damage). In case of oral intake, iodine can cause damage to the digestive tract, disturbance of thyroid function, cardiovascular disorder, metabolic disorders and damage to blood, liver and kidneys.

Iodine is highly hazardous to water supplies, even in small quantities. Leakage into water, sewerage systems or soil must be prevented.

MERCURY [Hg]

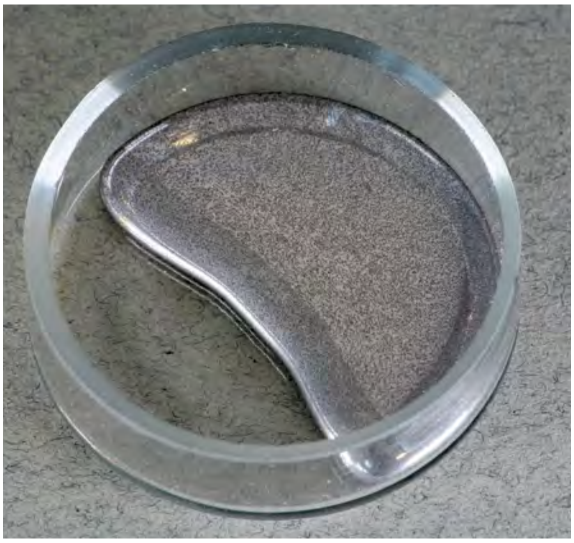


Image 103. Mercury
(source: Bundeswehr CBRN Defence Command ©)

Mercury is used in medical thermometers, switches (e.g. tilt switch) and disinfectants, for electrolysis in the chemical industry, bleaches and different lamps (e.g. fluorescent lamps). The metal can be encountered in areas where cold extraction is carried out. Mercury is required to produce the primary explosive mercury (II) fulminate.

Mercury is a shiny, silvery, odourless, liquid metal. It is non-combustible and does not dissolve in water. Mercury is heavier than water. It is very slightly volatile but may gradually evaporate at room temperature; in closed environments, this may generate hazardous concentrations of mercury in the air.

CHEMICAL BEHAVIOUR

An explosion or violent reaction can occur if mercury comes into contact with alkali metals, amines, ammonium, acetylene, specific metals (e.g. aluminium), nitric acid, nitromethane and oxygen in combination with heat, picric acid or sodium carbide.

HINT. Drops of liquid mercury can be cleaned by using absorbents such as Mercurisorb™.

TOXIC BEHAVIOUR

Metallic mercury and its soluble compounds are very toxic. Mercury vapour causes chronic poisoning that results in restlessness, headaches, forgetfulness, respiratory distress, reaction of the mucous membranes of the eyes, trembling of the hands and eyelids, kidney damage and gradual deterioration of the central nervous system until death. A sign of mercury poisoning is a black mercury fringe on the gums. Soluble mercury compounds in doses of 0.2 g to 1.0 g cause severe symptoms of poisoning, leading to death within days.

WARNING. Metallic mercury is particularly dangerous as a vapour, less so as a finely dispersed liquid and of little danger as a compact liquid droplet. The greatest risk is by inhalation of concentrated vapours, especially from the heated liquid in the case of inadequate ventilation. In this case there is severe danger to life.

Suitable materials for containers are glass, ceramic, stainless steel and iron. Unsuitable materials are aluminium, copper, gold and its alloys, silver and its alloys, tin and its alloys, as well as zinc and zinc alloys.

Mercury is extremely hazardous to water supplies, even in small quantities. Leakage into water, sewerage systems or soil must be prevented.

NOTE. The finding of a (large) number of fluorescent lamps can be an indicator that mercury has been harvested to produce HMEs.

METHANOL [CHOH] OR WOOD ALCOHOL, CARBINOL, COLONIAL SPIRITS, METHYLATED SPIRITS

Image 104. Industrial methylated spirits (source: BCL ©)

Methanol is used to manufacture chemicals, to remove water from automotive and aviation fuels, to produce biofuels, as a solvent for paints and plastics and as an ingredient in a wide variety of products such as antifreeze.

Methanol is a colourless liquid with an odour ranging from pleasant to pungent, like that of ethyl alcohol. It is very volatile and easily flammable. Methanol completely mixes with water. Its fumes generate explosive vapours in contact with the air.

CHEMICAL BEHAVIOUR

An explosion or violent reaction can occur when methanol comes into contact with acids (e.g. nitric acid, sulfuric acid), alkali metals, hydrogen peroxide or perchlorates.

TOXIC BEHAVIOUR

Methanol can cause irritation to the eyes, depression of the central nervous system and systemic eye damage.

Unsuitable materials for containers are aluminium, magnesium alloys and zinc alloys. Plastics must be checked for resistance before use.

Suitable extinguishing agents are water (spray jet), dry extinguishing powder and carbon dioxide. Large fires should be fought with alcohol-resistant foam or sprayed water.

Methanol is highly hazardous to water. Penetration into water and sewage systems or soil must be avoided.

> **NOTE. Toxic methanol is added to ethanol in a number of industrial applications. An addition of methanol allows ethanol to be sold more broadly, without incurring the need for an alcoholic beverage tax (such as for beer, wine or gin). These mixtures are called denatured alcohols or methylated spirits. It is therefore likely that MA staff will come across industrial mixtures of methanol and ethanol, which have a typical purple colour from the denaturing process and are therefore easily recognisable.**

NITROCELLULOSE [$(C_6H_7(NO_2)_3O_5)_n$] OR GUN COTTON, CELLULOSE NITRATE, PYROXYLIN

Image 105. Unprocessed nitrocellulose
(source: Bundeswehr CBRN Defence Command ©)

Nitrocellulose is the commonly employed designation for nitrate esters of cellulose (cellulose nitrates). It is used for gunpowder and in the production of explosives. Improvised nitrocellulose, made by the nitration of cotton liners, is likely to contain impurities and excess nitrating agent, making it highly sensitive to heat / flame and auto-ignition over time.

Image 106. Drums used as containers for industrially produced nitrocellulose (source: FSD ©)

Image 107. Label on a drum used as a container for industrially produced nitrocellulose (source: FSD ©)

CHEMICAL BEHAVIOUR

Nitrocellulose is a solid consisting of white fibres. It is classified as an explosive, can self-ignite and can produce dust explosions. Nitrocellulose reacts to friction, heating or other sources of ignition with rapid decomposition and the formation of large quantities of gas. The commercial product must be phlegmatised with water or alcohol. Nitrocellulose with 13.3% nitrogen has an impact sensitivity of 3 J, its friction sensitivity is approx. 353 N. Depending on the moisture agents used, nitrocellulose's flashpoint is between 12°C and 35°C and it starts deflagration at between 160°C and 180°C. All nitrocellulose is soluble in acetone.

An explosion or violent reaction can occur when nitrocellulose comes into contact with acids, alkalis or oxidisers.

TOXIC BEHAVIOUR

Pure nitrocellulose is not toxic, but phlegmatisers, moisture agents, unwashed nitrogen impurities or products of decomposition can generate toxicity.

Nitrocellulose hazards to aquatic life are not documented. Penetration of water and sewage systems or soil should be avoided.

PHENOL [C_6H_5OH]

Image 108. Phenol
(source: Bundeswehr CBRN Defence Command ©)

Phenol is used to produce dyes, pharmaceuticals, disinfectants, plastics and preservatives.

Phenol consists of colourless crystals (but usually reddish due to detergents), which strongly etch skin and cause white spots. It dissolves, to a limited extent, in water and has an intense odour.

CHEMICAL BEHAVIOUR

Phenol is flammable, its vapours may form explosive mixtures with air when the substance is heated above its flashpoint (79°C). Contact with strong oxidisers and acids can lead to explosions or dangerous reactions.

An explosion or violent reaction can occur when phenol comes into contact with aluminium, formaldehyde, hydrogen peroxide, strong lyes or oxidisers.

TOXIC BEHAVIOUR

Phenol can cause corrosive effects on mucous membranes and skin, as well as serious eye damage. It can lead to central nervous system and cardiovascular system disorders and can damage the kidneys.

Suitable materials for containers are glass or stainless steel. Plastics must be checked for their resistance before use. Unsuitable materials are aluminium, copper, zinc and rubber.

Suitable extinguishing agents are water (spray jet), dry extinguishing powder and carbon dioxide. Large fires should be fought with alcohol-resistant foam or sprayed water.

Phenol is hazardous to water supplies.

POTASSIUM CHLORIDE [KCl] OR SYLVITE, NOSALT

This chemical does not meet the threshold criteria for GHS classification. However, chemical and toxicology information is available via data sheets on the internet.

Image 109. Potassium chloride
(source: Bundeswehr CBRN Defence Command ©)

Potassium chloride is used as a raw material for almost all potassium compounds and is a component of many fertiliser salts. It is used as a flavour enhancer and as a substitute for sodium chlorite in artificial food-grade salts (for instance NoSalt). It is used for the improvised manufacture of potassium chlorate.

Potassium chloride forms colourless-white, very salty-bitter tasting, water soluble crystals and has no odour.

CHEMICAL BEHAVIOUR

The substance is not flammable and cannot cause dust explosions.

Potassium chloride is slightly hazardous to water supplies.

SODIUM HYDROXIDE [NaOH] OR CAUSTIC SODA, LYE, ASCARITE, WHITE CAUSTIC, SODIUM HYDRATE

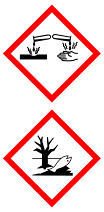


Image 110. Sodium hydroxide
(source: Bundeswehr CBRN Defence Command ©)

Sodium hydroxide is used to produce sodium salts, soaps, detergents, dyestuffs, as a confining liquor and to produce cellulose.

Sodium hydroxide is a white, crystalline, hygroscopic, highly corrosive mass. It can be found in the form of lumps, bars, scales or flakes. Dissolved in water, sodium hydroxide forms highly corrosive caustic soda. It dissipates in air while absorbing moisture and carbon dioxide from the atmosphere.

TOXIC BEHAVIOUR

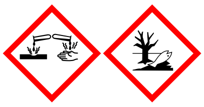
Sodium hydroxide can cause serious irritation and have a corrosive effect on all mucous membranes and skin, upon contact. It can lead to irreversible eye damage (risk of blindness).

Image 111. Bags of caustic soda flakes found in Mosul, Iraq (source: GICHD ©)

Unsuitable materials for containers are aluminium, brass, tin and zinc. Plastics must be checked for their resistance before use.

Sodium hydroxide is slightly hazardous to water supplies.

SODIUM HYPOCHLORITE [NaClO]



Sodium hypochlorite is used in bleaching agents, cleaning and disinfection agents for pools, fabrics and medicines. It is used for the improvised production of chlorates.

Sodium hypochlorite is a yellow liquid with a pungent stench. It can be stored only in aqueous solutions that, depending on their concentration, may be very caustic.

CHEMICAL BEHAVIOUR

Sodium hypochlorite can explode or react violently when in contact with acids, amines, ammonia, oxidisers and urea.

TOXIC BEHAVIOUR

Sodium hypochlorite can cause irritation and a corrosive effect on mucous membranes, the eyes and skin.

Suitable materials for containers are glass, ceramic and PE.

Sodium hypochlorite is highly hazardous to water supplies, even in small quantities. Leakage into water, sewerage systems or soil must be prevented.

TETRACHLOROETHYLENE [C_2Cl_4] OR PERC, PERCHLOROETHYLENE, TETRALEX®, TETLEN

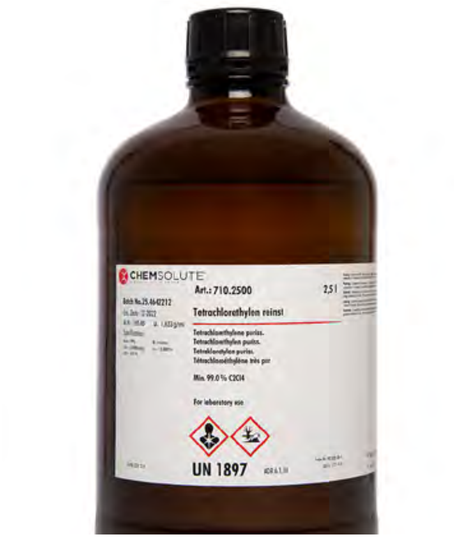


Image 112. Laboratory-grade tetrachloroethylene, 99%
(source: Th. Geyer Ingredients GmbH & Co. KG ©)

Tetrachloroethylene is mainly used as a cleaning solvent in dry cleaning and textile processing and in the manufacture of fluorocarbons. The presence of tetrachloroethylene can be an indicator of the production of improvised liquid explosives.

Tetrachloroethylene is a colourless, volatile, non-flammable liquid, with an ether-like odour that may emit toxic fumes of phosgene when exposed to sunlight or flames.

CHEMICAL BEHAVIOUR

An explosion or violent reaction can occur when tetrachloroethylene comes into contact with alkali metals, strong lyes, strong oxidisers or powdered metals.

TOXIC BEHAVIOUR

Tetrachloroethylene can cause irritation of mucous membranes and skin, impairment of the central nervous system and, with high exposure, impairment of liver and kidney function.

Tetrachloroethylene is highly hazardous to water supplies, even in small quantities. Leakage into water, sewerage systems or soil must be prevented.

UREA [$CO(NH_2)_2$]

This chemical does not meet the threshold criteria for GHS classification. However, chemical and toxicology information is available via data sheets on the internet.

Image 113. Urea
(source: Bundeswehr CBRN Defence Command ©)

Urea is used in fertilisers, fire extinguishing powder, de-icing agents, fuel additives (e.g. AdBlue®), cosmetics and medical products. It is a precursor for urea nitrate.

Urea is a white, crystalline powder with a faint ammonia-like odour. It is a non-flammable substance, easily soluble in water and is hygroscopic. Urea cannot cause dust explosions.

CHEMICAL BEHAVIOUR

An explosion or violent reaction can occur when urea comes into contact with ammonium nitrate, hydrogen peroxide, perchlorates (sodium perchlorate), strong oxidisers, sources of chloride or titan tetrachloride.

Urea is slightly hazardous to water supplies.

4.6. EFFECTS OF AGEING

This sub-section presents the issue of ageing, and the effect of ageing on HMEs. This particular process is not well documented in the case of a number of HMEs and so, due to the lack of information, more general observations will be provided.

The effects of ageing impact the performance and safety of all ammunition components.

Besides explosive ordnance itself, fillers and the components of fuzes also age. In general, the effects of ageing on military ordnance are well documented. In this context, diurnal cycling, which is the exposure of ammunition and explosives to the temperature changes induced by day, night and change of season, is known to be a potential issue.

An industrially produced explosive must fulfil stringent criteria in terms of ageing so that accidents in storage, handling and use are minimised throughout its service life. HMEs are not manufactured to such standards. In general, ageing of HMEs should not be equated with an increase in safety, but quite the opposite. Consequently, unidentified HMEs showing signs of ageing must not automatically be considered stable or desensitised.

Image 114. Effects of ageing visible on pyrotechnic time fuzes (source: GICHD ©)

Image 115. Aged artillery shell with anti-personnel effect in sandy soil. The shell was exposed to an explosion 65 years prior to its finding. The greyish-yellow TNT filler, exposed to the environment, is partly visible amongst the fragmentation balls (source: GICHD ©)

Reliable studies on the effects of ageing on the explosive properties of HMEs are rare; where they do exist, most information is classified. Besides exposure to a variety of environmental effects (such as humidity or solar rays, for instance) or a possible chemical decay over time, diurnal cycling can age HMEs.

Whilst some HMEs may lose their explosive properties over time, they may still present specific toxic and caustic hazards. In addition, chemical decay may lead to the strengthening or formation of new toxic or caustic hazards. These effects may be supported or accelerated by the material of a casing or container. In addition, the disintegration of a container may influence further effects of ageing on HMEs much more than on military-grade ammunition.

- Ageing can have a big impact on the stability and sensitivity of HMEs and their precursor chemicals.
- HMEs may corrode and lead to the deterioration of container material, switches, detonator casings and so on.
- The absorption of water can desensitise HMEs; oxidisers or fuels may react with water.
- Chemicals can be affected by heat and solar radiation, which can lead to increased or decreased sensitivity and decreased stability.
- Diurnal cycling (temperature differences between day and night) can break apart explosive fillings within containers, increasing sites for hotspot generation in handling and transport.
- The presence of impurities, explosives used in boosters or additives, can lead to further chemical reactions, creating unstable substances over time.
- Desensitisers and plasticisers can vaporise, increasing sensitivity and decreasing stability.
- Cracks and fractures accelerate the burning behaviour of propellants in an uncontrolled manner.
- Some HMEs can vaporise and recrystallise, or form unstable, reactive salts, some with explosive properties, such as ammonium chlorate and copper azide.
- Some HMEs may have dissolved in water and then solidified again, building more sensitive, unstable structures.
- The concentration of phlegmatisers in an HME can decrease, leading to increased sensitivity.
- Because of the hygroscopic effect, water absorption in an HME can lead to caking, thereby increasing explosive performance (e.g. ammonium nitrate).
- Impurities, for instance in (reused) containers, may accelerate or magnify the effects of ageing as well.

WARNING. The uptake of moisture in the outer exposed layers of some HMEs can lead to the creation of a solid crust when exposed to rain, followed by sun or heat. This can increase the density of an explosive or alter the chemical balance between fuel and oxidiser. To avoid any unwanted energetic decomposition, this crust should not be broken with mechanical force.

Image 116. Cocked striker of a VS-500 corroded by ageing (source: FSD ©)

Image 117. Effects of ageing: aluminium powder after separation from ammonium nitrate (source: FSD ©)

Image 118. Ageing: unknown mining explosive aged after being stored in a non-air-conditioned container in a tropical location for an unknown time. The casing is destroyed and discoloration of the explosive is recognisable. The chemical effects of ageing on the explosive cannot be estimated (source: Stanislav Damjanovic ©)

Image 119. Effects of ageing: recrystallised ammonium nitrate (source: FSD ©)

Image 120. Drum of hydrogen peroxide reused as a canister for an HME main charge. Hydrogen peroxide remnants may influence an HME's ageing as well (source: FSD ©)

5. HOME-MADE EXPLOSIVES

Given the vast number of fuels and oxidisers that may be used in HME manufacture, this section focuses on the main types of HME that mine action (MA) staff may encounter. It will outline their common characteristics, applications and hazards, considering the limitations in obtaining these data.

Sections 3 and 4 of this chapter have provided details on the outward appearance, specific risks and hazards of precursor chemicals, whilst this section will provide information on how variables such as particle size, quality of raw materials, and impurities will affect an HME's chemical properties. Identical HMEs may present different colours, appearance and smell, since manufacturers may attempt to disguise them to hamper search efforts.

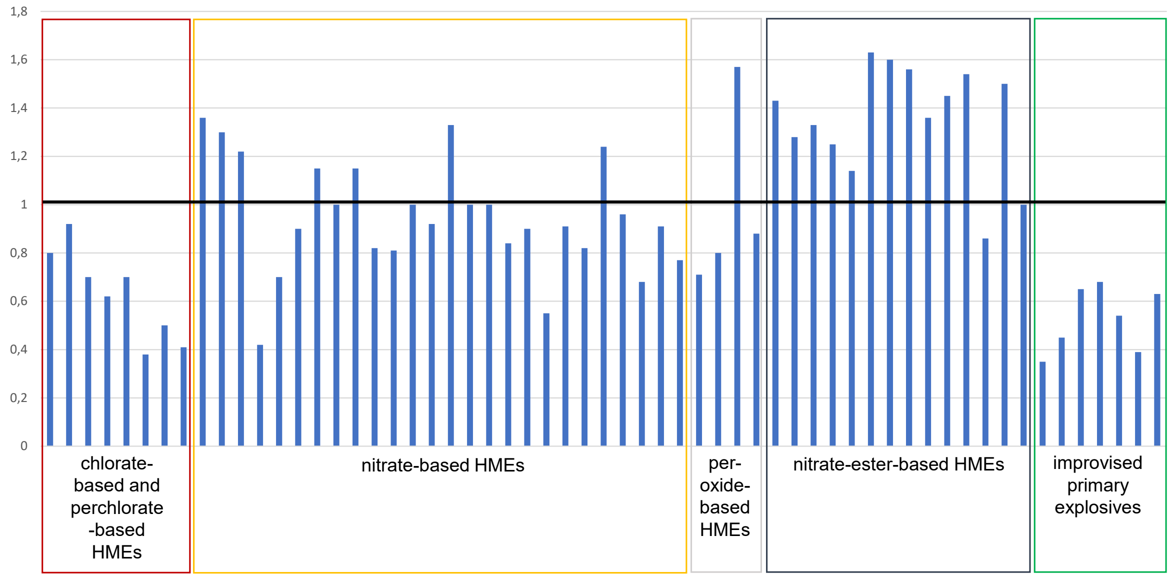


Table 10. Most common groups of high-explosive HMEs, compared to their TNT equivalent (TNT =1) (source: BCL ©)

Table 10 illustrates the variation in performance of many thousands of HME compositions that have been encountered in both military and MA operations globally. Based on the content of Table 10, unknown HME compositions / mixtures should be treated as if they were approximately 1.5 times their TNT equivalent, for evacuation purposes.

NOTE. It is of critical importance to bear in mind that the detonation parameters, sensitivity and stability of HMEs depend greatly on:

- **Components' shape, size, porosity;**
- **Ratio of fuel to oxidiser;**
- **Water content and impurities;**
- **Charge diameter;**
- **Confinement conditions (including type and thickness of container material); and**
- **Influence of additives.**

WARNING. HMEs must not be considered safer to handle just because they are reported as non-cap sensitive.

No safety data sheets are available for the majority of improvised explosives. To emphasise their possible hazards, the GHS classification of their precursor chemicals is added to the enumerations in this section. It can be assumed that HMEs follow at least the same GHS classification as their precursor chemicals. Furthermore, as a warning and a reminder, the pictogram GHS 01 (exploding bomb – unstable explosive) is added as well.

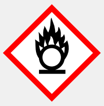
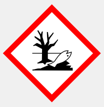
HME – PRECURSOR A – PRECURSOR B – PRECURSOR C			
HME	precursor A	precursor B	precursor C
	  		 

Table 11. Example of GHS classifications of an HME and its precursor chemicals as used in this section

5.1. CHLORATE AND PERCHLORATE-BASED HMEs

Chlorate explosives are explosive mixtures of chloric acid salts (alkali metal chlorates) and carbon-rich organic fuels. They are more sensitive to impact than nitrate-based HMEs.

Claude-Louis Berthollet was the first to discover the energetic properties of potassium chlorate when mixed with fuels. The explosive mixture of potassium chlorate–sulphur–charcoal was introduced as Berthollet powder in 1785. Commercially applied chlorate explosives are ‘rack-a-rock’ or ‘cheddite’. Chlorate explosives (for instance Jonkit or Lyddite) were in use by the military until the Second World War.

Today, chlorates are not used in commercial or military explosives due to their high sensitivity and low performance compared to other, more modern chemicals.

NOTE. The use of chlorate- or perchlorate-based HMEs has increased in countries and / or conflicts where ammonium nitrate is banned as a fertiliser or where its use is regulated by government legislation.

Perchlorate explosives are explosive mixtures of perchloric acid salts and carbon-rich fuels. They are more sensitive to impact and friction than nitrate-based HMEs. Nowadays, commercial perchlorate explosives are no longer produced, as their use is considered uneconomical.

Most mixtures of chlorates / perchlorates and organic fuels are cap sensitive, with the degree of sensitivity depending on the types of organic fuel used:

• nitromethane	very sensitive
• oil, diesel	sensitive

Perchlorate mixtures are considered more stable than chlorate mixtures but must also be considered extremely sensitive to impact, friction, electric discharge / sparks and heat.

NOTE. When encountering chlorate- or perchlorate-based HMEs, it is essential to be aware of their sensitivity and understand that a presence of impurities (which will make them even more sensitive) is difficult to predict.

5.1.1. POTASSIUM CHLORATE-BASED HMEs

POTASSIUM CHLORATE

Image 121. Potassium chlorate (source: BCL ©)

Potassium chlorate is a stable, white, crystalline solid, with low toxicity, commonly used as an oxidising agent in the preparation of oxygen, and as a disinfectant. It is a powerful oxygen donor with 39.2% oxygen by weight and is the principal component of chlorate-based explosives, incendiaries, primer formulations, pyrotechnics and match head compositions.

Potassium chlorate itself does not burn but reacts so violently with flammable substances that it can cause them to ignite, sometimes without any further ignition source, and can considerably promote an existing fire. Compared to perchlorates or nitrates, potassium chlorate-based HMEs are very sensitive, as Table 8, in section 4, demonstrates.

Potassium chlorate is more sensitive due to its low melting point and low decomposition temperature. Due to these physical characteristics, very little energy is required to start an exothermic decomposition. The process becomes even more volatile if low melting point fuels are also used – under such circumstances, the mixture may explode by friction or light impact.

WARNING. The simultaneous presence of ammonium nitrate and potassium chlorate poses a high risk. Both chemicals react with moisture to form ammonium chlorate, which spontaneously decomposes in an explosive manner. These HMEs should never, under any circumstance, be transported or stored together.

POTASSIUM CHLORATE–ALUMINIUM

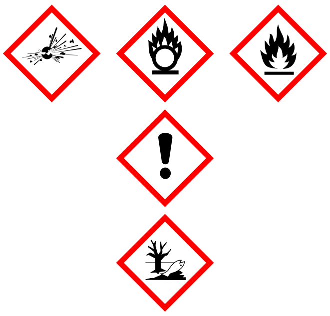


Image 122. Potassium chlorate–aluminium
(source: BCL ©)

This improvised explosive is a grey-silver, dark grey to almost black powder. The finer the aluminium is ground, the more reactive this mixture is and the darker its appearance.

NOTE. Potassium chlorate mixed with other metal powders will also form HME.

POTASSIUM CHLORATE–ALUMINIUM–SULPHUR

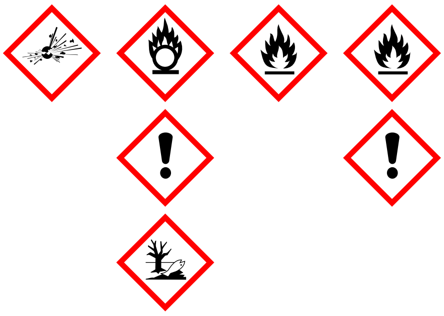
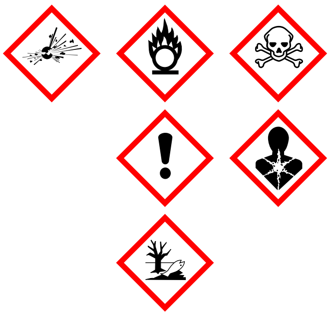


Image 123. Potassium chlorate-aluminium-sulphur
(source: BCL ©)

This improvised explosive is a grey, granular or fine powder mixture. It has a very low ignition temperature. It is very sensitive and unstable.

POTASSIUM CHLORATE–NITROBENZENE OR RACK-A-ROCK



This improvised explosive is a slurry-like mixture that has a yellow-white appearance, with an almond odour. This HME is sensitive to heat, shock and friction.

POTASSIUM CHLORATE–PARAFFIN (BABY OIL) OR PETROLEUM JELLY

Image 124. Potassium chlorate-petroleum jelly
(source: BCL ©)

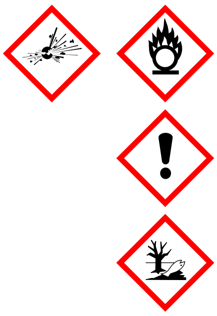


Image 125. Potassium chlorate-petroleum jelly
(source: BCL ©)

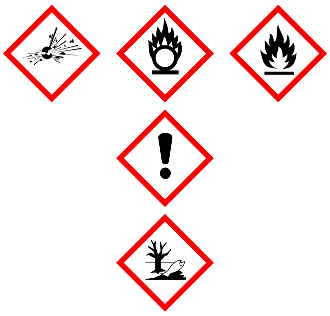
In both cases (mixed with paraffin or petroleum jelly), this improvised explosive is a whitish, putty-like solid or clump. It is used to make improvised plastic explosives and known as ‘the poor man’s C4’.

Depending on the amount of fuel, the HME is of a plastic to semi-plastic consistency. Both mixtures, potassium chlorate–paraffin and potassium chlorate–petroleum jelly, are considered moderately sensitive to mechanical stimuli. The impact sensitivity of paraffin mixtures is higher than the impact sensitivity of petroleum jelly mixtures.

The oxidiser to fuel ratio alters the strength of the HME. Potassium chlorate–paraffin mixtures reach a detonation velocity of up to 3620 m/s, whilst potassium chlorate–petroleum jelly mixtures reach a detonation velocity of up to 3140 m/s. As a comparison, military-grade C4 (Hexogen with binders and plasticisers) has a detonation velocity of up to 8000 m/s.

POTASSIUM CHLORATE–RED PHOSPHORUS

Image 126. Armstrong's mixture
(source: Bundeswehr CBRN Defence Command ©)



This improvised explosive is a red, granular or fine powder mixture also known as 'Armstrong's mixture' which is very unstable and sensitive. Some manufacturers even add sulphur to increase the sensitivity.

Armstrong's mixture is considered one of the most dangerous potassium chlorate mixtures and is one of the common flash compositions (or flash powders). Because of the red phosphorus, it is extremely sensitive to heat and friction and sensitive to electrostatic discharge. It is known to decompose violently during the production process. Extreme care must be taken when handling it as it may detonate from slight shock or touch; its reaction is unpredictable. Armstrong's mixture is used for matches and toy gun caps. This HME can be used as a primary explosive.

Armstrong's mixture is used for metal-free initiation elements. MA staff may encounter this HME when finding mechanical / pressure-initiated or crush sensitive initiators.

⚠ **WARNING. A mixture of potassium chlorate and red phosphorus must not come into contact with concentrated sulfuric acid, as a violent reaction may occur.**

POTASSIUM CHLORATE–SUCROSE / SUGAR

Image 127. Potassium chlorate–cane sugar
(source: BCL ©)

This improvised explosive is a white-grey to brownish-grey, granular or fine powder mixture. The type of sugar used (for instance white vs brown sugar) can change its colour. Commercially, this composition is used in signal smoke charges. It has a low ignition temperature and is considered sensitive.

Combinations of potassium chlorate, sugar and sulphuric acid can be encountered. These mixtures may ignite instantaneously.

5.1.2. SODIUM CHLORATE-BASED HMEs

SODIUM CHLORATE

Pure sodium chlorate has no explosive properties. When mixed with red phosphorus, sulphur or sugar, the reactivity and hazards of sodium chlorate combined with fuels, are considered equal to those of potassium chlorate-based HMEs.

SODIUM CHLORATE–ALUMINIUM

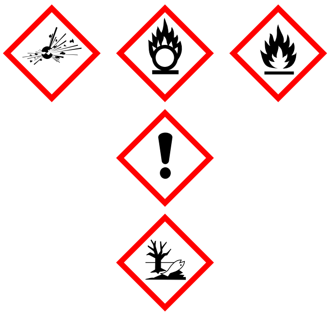


Image 128. Sodium chlorate–aluminium
(source: BCL ©)

This is a silver to black crystalline or granular solid with an undefined odour. It is an explosive and flammable material. Sodium chlorate–aluminium mixtures were historically used for flash powders but have been used as propellants and incendiaries in recent HME compositions. Detonation is highly likely in confinement and with the appropriate critical diameter and loading density.

SODIUM CHLORATE–KEROSENE

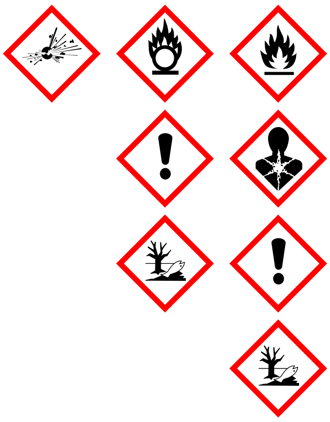


Image 129. Sodium chlorate–kerosene
(source: Bundeswehr CBRN Defence Command ©)

This is a white or yellow-brown crystalline or granular solid with an undefined odour. It is an explosive and flammable material.

SODIUM CHLORATE–NITROBENZENE

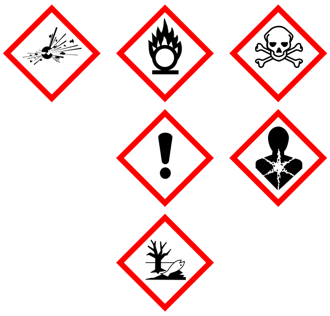


Image 130. Sodium chlorate–nitrobenzene
(source: Bundeswehr CBRN Defence Command ©)

This is a white-yellow, crystalline solid. It may spontaneously ignite when mixed with ammonium nitrate.

⚠ NOTE. This HME is referred to as 'Co-Op' or 'Co-Op Sugar' because of its use in an attack against the Belfast Co-Operative Society store by the Provisional Irish Republican Army (IRA) in 1972.

5.1.3. AMMONIUM PERCHLORATE-BASED HMEs

AMMONIUM PERCHLORATE

Ammonium perchlorate is a very reactive solid with explosive properties that reacts upon impact, friction, heating and other sources of ignition, with a violent decomposition forming large quantities of gas. It is easily soluble in water.

Ammonium perchlorate itself does not burn but reacts so violently with flammable substances that it may cause them to ignite without any other source of ignition, and may considerably promote an existing fire. When ammonium perchlorate is mixed with flammable powdery substances, explosions may occur.

Non-stabilised ammonium perchlorate is a dangerous explosive. In a stabilised state (for example with 10% water), it is not explosive but does promote fire. When mixed with organic substances, both stabilised and non-stabilised ammonium perchlorate have explosive properties.

AMMONIUM PERCHLORATE–ALUMINIUM

Image 131. Ammonium perchlorate–aluminium
(source: Bundeswehr CBRN Defence Command ©)

This improvised explosive varies from a white, silver or grey to an almost charcoal-coloured granular mixture. The finer the aluminium is ground, the more reactive it is and the darker it looks. This HME is extremely sensitive to heat, shock and friction.

AMMONIUM PERCHLORATE–SOAP

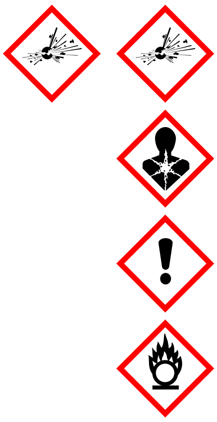


Image 132. Ammonium perchlorate–soap
(source: Bundeswehr CBRN Defence Command ©)

This improvised explosive is a paste / putty-like solid. Depending on the soap used, its colour varies from white, beige, light green to brown. Its odour also varies. This HME is flammable and explosive.

5.1.4. POTASSIUM PERCHLORATE-BASED HMEs

Image 133. Sodium chlorate–petroleum jelly, demonstrating the identical appearance to that of potassium perchlorate–petroleum jelly (source: BCL ©)

Potassium perchlorate–fuel mixtures are slightly less sensitive than potassium chlorate–fuel mixtures given the higher thermal decomposition temperature of the former (610°C as opposed to 356°C).

The possible HME mixtures and their performance, are equal to those listed in sub-section 5.1.1. (potassium chlorate-based HMEs) above, (including improvised plastic explosives).

Potassium perchlorate is highly incendiary but has a good shelf life. Mixtures with sulphur, phosphorus and metal powders ignite at low temperatures. These can be made to explode with a simple hammer blow.

NOTE. Potassium / sodium chlorate and potassium / sodium perchlorate HME mixtures are extremely difficult to tell apart without a chemical analysis and similar in appearance (see image 125 and image 133). For this reason, no additional photography is provided of sodium perchlorate or ammonium perchlorate HME mixtures. All compounds that are thought to be of chlorate or perchlorate origin should be treated as potassium chlorate HME mixtures.

5.2. NITRATE-BASED HMEs

Nitrate-based explosives are explosive mixtures of nitric acid salts and carbon-rich liquid or solid fuels. They are quite insensitive to impact and friction, with HME mixtures often requiring a booster, depending on the type of nitrate and fuel used.

Johann Rudolph Glauber[52] was the first person to manufacture ammonium nitrate. The first explosive using ammonium nitrate was patented in 1876 by two Swedish scientists. Military-grade ammonium nitrate was used up until the Second World War in secondary explosives and propellants, such as alumatol, amatex, amatol and ammonal. Ammonium nitrate is used in commercial explosives, such as for mining. These commercial explosives, like ammonia dynamite or ammonia gelignite, are manufactured as powders, prills, gels or slurries. Today, ammonium nitrate's use in HMEs is widespread given its availability worldwide, based on its use in fertilisers.

WARNING. The safety standards for commercial ammonium nitrate explosives (for instance safe to handle, safe to move) must not be considered sufficient for ammonium nitrate-based HMEs. Developing a false sense of safety can be fatal to MA staff.

5.2.1. AMMONIUM NITRATE-BASED HMEs

The majority of ammonium nitrate used in HMEs is harvested from fertilisers, from stolen technical-grade ammonium nitrate (for use as a commercial explosive) or from cool packs from medical supply chains. The use of ammonium nitrate in HMEs is very cheap compared to other oxidisers. This compensates for the disadvantage that some compositions require very large explosive charges to be able to detonate.

Ammonium nitrate is very hygroscopic. In pure powder or crystalline form, it cakes during storage. It is highly soluble in water; for instance, 1.8 kg can be dissolved in 1 litre of 20°C warm water. Pure ammonium nitrate is extremely difficult to detonate on its own. As such, ammonium nitrate-based HMEs are generally mixtures of ammonium nitrate with 2%–10% carbon carriers such as sawdust, oil or coal. Ammonium nitrate is also employed to modify the detonation rate of other explosives, such as nitroglycerine in the so-called ammonia dynamites, or as an oxidising agent in ammonals, which are mixtures of ammonium nitrate and powdered aluminium. In the latter case, the power of ammonium nitrate (heat of explosion and volume of gaseous products produced) is enhanced. It can also be found mixed with TNT, which, in this case, acts as a sensitiser.

WARNING. Ammonium nitrate–potassium chlorate mixtures may also be encountered, and which can become dangerously unstable. Ammonium chlorate, formed on contact of these two substances, tends to detonate spontaneously. It is important to be aware that this formation will occur on contact of ammonium nitrate with any chlorate source. As an effect of ageing, the formation of ammonium chlorate makes the stability of such mixtures impossible to assess; therefore, ammonium nitrate and ammonium chlorate should never be transported or stored together.

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[52] Glauber was a German pharmacist and chemist who developed different measures to produce acids and salts.

Image 134. Ammonium nitrate–potassium chlorate mixture. Remark: this mixture was processed under laboratory conditions (source: Bundeswehr CBRN Defence Command ©)

Pure ammonium nitrate has an impact sensitivity of 49 J and a friction sensitivity of 353 N, which may increase depending on fuels, additives and impurities. For example, Ammonit3, a commercially used ammonium nitrate explosive with additives including aluminium, has an impact sensitivity of 12 J.

WARNING. Ammonium nitrate is highly reactive with copper and zinc. Such mixtures are very unstable and will explode on heating. MA staff must take this into consideration if / when required to handle, move or dispose of such substances.

The vast majority of ammonium nitrate-based HME mixtures (except ammonium nitrate-aluminium ANAL and ammonium nitrate–nitromethane ANNM) are generally insensitive to initiation by detonator alone and require confinement and a booster. Hence, ammonium nitrate–fuel oil (ANFO), ammonium nitrate–nitrobenzene (ANNIE), ammonium nitrate–sugar (ANS) and ammonium nitrate–icing sugar (ANIS) are termed tertiary explosives. These mixtures have a low detonation velocity (so are unsuitable for driving anti-armour penetrators such as shaped charges and explosively formed projectiles), are not easily initiated in small quantities but do have a specific impulse similar to TNT, which makes them good for blast-related applications. Practical experience of ammonium nitrate HME mixtures (except for ANAL and ANNM) demonstrates that they are insensitive to initiation from 0.5 calibre rounds.

Image 135. Explosive formed projectile plate, Mosul, Iraq
(source: GICHD ©)

Ammonium nitrate is not an ideal explosive, because charges require a high degree of confinement and a large critical diameter. For this reason, charges in excess of 20 kg are usually encountered. Ammonium nitrate with a 1.4 g/cm^3 density is listed with a detonation velocity of 2500 m/s. A higher detonation velocity of up to 3500 m/s can be achieved depending on the fuels used.[53]

SOLID ORGANIC / INORGANIC FUELS

Compared to other HMEs, the production and handling of ammonium nitrate–organic / inorganic solid fuel HME mixtures is considered safe. In general, these HMEs are cap sensitive but require a booster to ensure a complete decomposition. They have low sensitivity and are physically stable.

SOLID METALLIC FUELS

In general, these HMEs are cap sensitive and may not require a booster, since the metal particles create sites of friction promoting the development of hotspots. This behaviour depends on loading density and particle size of the metallic fuel. Ammonium nitrate–metal fuel mixtures have a greater sensitivity than those with organic fuels but still remain physically stable. Viable charges weighing less than 20 kg have been encountered.

LIQUID FUELS

Liquid HME compositions such as ANNM are less physically stable and are cap sensitive.

The sensitivity and strength of ammonium nitrate-based HMEs is very much driven by type of fuel, loading density and the presence of air bubbles (which favours hotspot generation). Liquid fuels can soak effectively into both powder and porous prills displacing the air present in the pores, thus ensuring close contact between fuel and oxidiser. This simplifies an initiation of the explosive mixture compared to other fuels. Powdered fuels cannot soak into powder or porous prills and are therefore not as effective in mixing.

⚠ **HINT. Quality, content and hazards of industrially packaged chemicals can be investigated using information provided on packaging labels, including pictograms, markings, batch / lot / serial number(s), production dates, barcodes, etc. Depending on the producer, safety data sheets may be available even on a company's website. Therefore, it is good practice to collect all information provided on chemical packaging.**

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[53] UK Defence Evaluation and Research Agency (DERA), Physical and chemical evidence remaining after the explosion of large, improvised bombs (DERA/CES/FEL/CR9802 dated March 1998).

EXAMPLE: LABELLING OF FERTILISERS

Ammonium nitrate is a source of nitrogen in fertilisers but not all fertilisers containing nitrogen use ammonium nitrate. For this reason, it is useful to know the nomenclature used for fertilisers, to be able to assess possible hazards and content. Fertilisers are labelled with a so-called NPK number, a three-digit code that expresses the ratio of three plant nutrients in the following order: nitrogen N; phosphorus P; and potassium K.

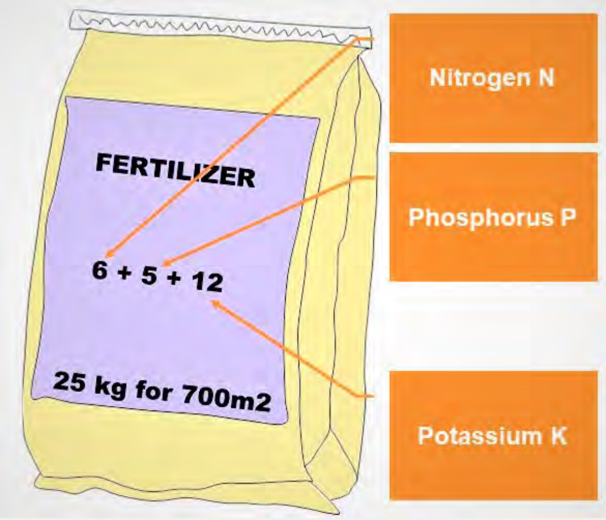


Figure 7. Example of NPK labelling on a bag of fertiliser (source: GICHD ©)

Image 136. Labelling on a bag of potassium nitrate (source: CAR ©)

N refers to the % ratio of nitrogen sources, such as ammonium nitrate or urea.
P refers to the % ratio of phosphorus sources, such as phosphorus pentoxide.
K refers to the % ratio of potassium sources, such as potassium oxide.
The NPK number may be labelled as N-P-K, N:P:K or N+P+K.

Not all fertilisers with nitrogen include ammonium nitrate. The NPK number can reveal the content, as follows:

Ammonium phosphate	NPK 16-20-0
Ammonium sulphate	NPK 21-0-0
Calcium ammonium nitrate	NPK 27-0-0
Ammonium nitrate	NPK 34-0-0
Urea	NPK 46-0-0

The labelling of ammonium nitrate fertilisers can sometimes be misleading. For example, the mass percentage of nitrogen in pure ammonium nitrate is 35%. In this form it is extremely difficult to detonate unless confined and exposed to an appropriate stimulus. Research has shown that if the ammonium nitrate content in a fertiliser is limited to 80% of weight concentration (the mass percentage of nitrogen is 28%) then its ability to detonate is much reduced.

Technical-grade ammonium nitrate will generally contain very high concentrations of ammonium nitrate (above 80%), which is why it is so effective in blasting applications when mixed with fuel oil. It is therefore important to understand the percentage figure that is displayed on any recovered ammonium nitrate packaging, to understand the potency of potential ammonium nitrate-based HME mixtures that may be encountered. Indeed, packaging sometimes indicates the weight concentration, while at other times it displays the nitrogen content. The ammonium nitrate bag in the picture, below, shows ammonium nitrate “AN % 33 N”, which means that the fertiliser contains approximately 94% ammonium nitrate by weight (33/35 x 100%), a very good source of ammonium nitrate for HME use.

Image 137. Fertiliser-grade ammonium nitrate recovered in Iraq (source: CAR ©)

Image 138, below, identifies an ammonium nitrate source that states ‘not less than 98.5%’. This means that the source of ammonium nitrate is 98.5% ammonium nitrate mixed with other additives. As such, this means that the source contains at least a mass percentage of nitrogen of 34.5% and is therefore way above a mass percentage of nitrogen of 28%, making it another excellent source for HME applications.

Image 138. High nitrogen content fertiliser in a contaminated state (source: BCL-FA ©)

AMMONIUM NITRATE–ALUMINIUM [ANAL]

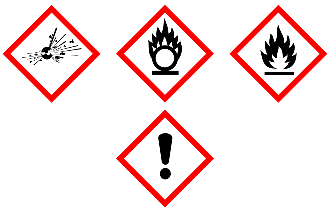


Image 139. Ammonium nitrate–aluminium
(source: Bundeswehr CBRN Defence Command ©)

ANAL is a white-grey or charcoal-coloured, loose prill or granular powder mixture. It is odourless but can have a faint hydrocarbon smell (aromatic, benzine-like) if mixed with fuel oils. ANAL is a very powerful explosive mixture, given that the aluminium adds to the heat of explosion. ANAL is flammable and can be encountered as small charges. It has a higher strength than pure ammonium nitrate.

AMMONIUM NITRATE–FUEL OIL [ANFO OR ANC]

Image 140. Ammonium nitrate prills with fuel oil (source: Bundeswehr CBRN Defence Command ©)

Image 141. Crystalline ammonium nitrate–fuel oil (source: Bundeswehr CBRN Defence Command ©)

Image 142. Ammonium nitrate–fuel oil with HMTD booster (source: BCL ©)

ANFO can be a cream-coloured, brown, pink or orange HME, depending on the fuel and other additives used. Its appearance can be as prills or a paste-like solid. When mixed with diesel, it can be oily with an ammonia or hydrocarbon smell. ANFO is flammable.

HINT. For the disposal of ANFO, it is essential to be aware that:
- Improvised ANFO is a tertiary explosive and requires a booster.
- Improvised ANFO cannot be initiated in small quantities and requires some measure of confinement.
- Without confinement, it is likely that improvised ANFO may just be scattered over the area due to incomplete detonation, unless there has been significant caking.

AMMONIUM NITRATE–NITROBENZENE [ANNIE]

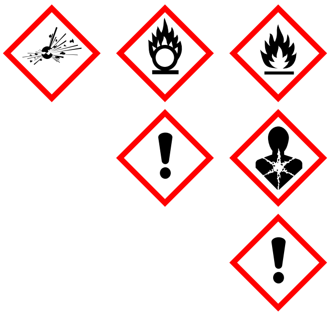


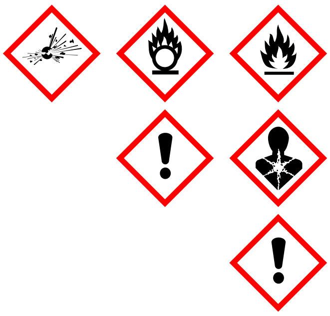
Image 143. Ammonium nitrate–nitrobenzene
(source: Bundeswehr CBRN Defence Command ©)

ANNIE is a cream-yellow or light grey-brown, crystalline solid with a variety of odours depending on the nitrobenzene source. Odours may be almond, marzipan or mild and fruity. In general, the odours are described as unpleasant.

ANNIE is more shock sensitive than ANFO.

AMMONIUM NITRATE–NITROMETHANE [ANNM]

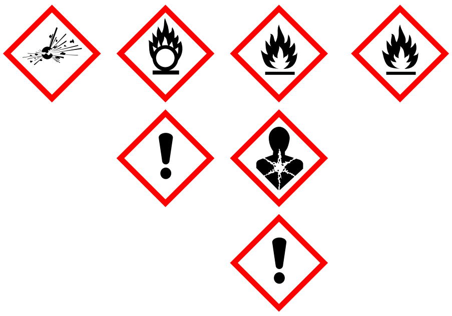
Image 144. Ammonium nitrate–nitromethane
(source: Bundeswehr CBRN Defence Command ©)



This cap-sensitive mixture can be improvised but is commercially available as well, for instance KINEPAK®. Commercial KINEPAK® is a binary explosive, with ammonium nitrate and nitromethane packed separately and mixed prior to use.

ANNM is a white-light pink explosive with the appearance of wet sand or toothpaste when mixed. In general, ammonium nitrate is used as powder. It is considered very insensitive and stable at normal temperatures and pressure, and it is cap sensitive. Contact with combustible materials, metals, metal salts, fuels and oxidisers should be avoided.

AMMONIUM NITRATE–NITROMETHANE–ALUMINIUM [ANMAL]



ANMAL is a white-grey to charcoal-coloured explosive, with the appearance of wet sand or toothpaste when mixed. It is cap sensitive and does not require a booster.

AMMONIUM NITRATE–SUGAR [ANS / ICING SUGAR ANIS]

Image 145. Ammonium nitrate–sugar
(source: Bundeswehr CBRN Defence Command ©)

ANS is a white-cream-coloured granular and / or powder mixture; the sugar influences the mixture's appearance. ANS / ANIS requires a booster.

OTHER AMMONIUM NITRATE–FUEL MIXTURES ENCOUNTERED:

AMMONIUM NITRATE–CARBON POWDER

Image 146. Ammonium nitrate–powdered charcoal
(source: Bundeswehr CBRN Defence Command ©)

AMMONIUM NITRATE–MAGNESIUM POWDER

Image 147. Ammonium nitrate–magnesium powder
(source: Bundeswehr CBRN Defence Command ©)

AMMONIUM NITRATE–SAWDUST

Image 148. Ammonium nitrate–sawdust
(source: Bundeswehr CBRN Defence Command ©)

AMMONIUM NITRATE–TNT [AMATOL]

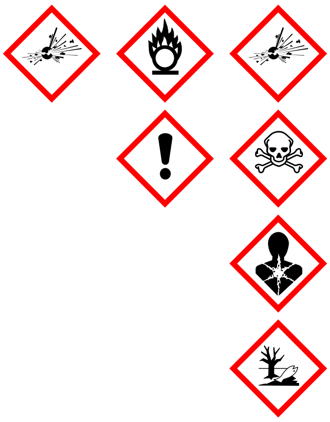


Image 149. Ammonium nitrate–TNT
(source: Bundeswehr CBRN Defence Command ©)

AMMONIUM NITRATE–UREA

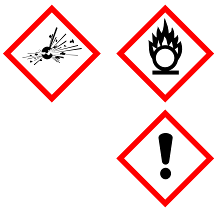


Image 150. Ammonium nitrate–urea
(source: Bundeswehr CBRN Defence Command ©)

5.2.2. CALCIUM AMMONIUM NITRATE (CAN)- BASED HMEs [54]

CALCIUM AMMONIUM NITRATE

Image 151. Calcium ammonium nitrate, processed as prills (source: Bundeswehr CBRN Defence Command ©)

Image 152. Calcium ammonium nitrate, possible appearance (source: Bundeswehr CBRN Defence Command ©)

Calcium ammonium nitrate ($CaCO_3$ & NH_4NO_3) is ammonium nitrate mixed with limestone or dolomite. It is used as a fertiliser, consisting of grey-brown prills with a dirty appearance.

Sometimes, manufacturers will separate calcium and ammonium nitrate. Within certain parameters this fertiliser can be used as an oxidiser for HMEs without any further processing.

Possible fuels are those used with improvised ammonium nitrate HMEs, such as those listed in subsection 5.2.1 – ammonium nitrate-based HMEs. Due to the calcium additive, these HMEs are less sensitive than comparable ammonium nitrate HMEs and require confinement, a booster and a large critical diameter.

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[54] The GHS classification represents the hazards after the calcium’s reduction / removal.

5.2.3. METHYL NITRATE-BASED HMEs

METHYL NITRATE

Image 153. Methyl nitrate
(source: Bundeswehr CBRN Defence Command ©)

Methyl nitrate (CH_3NO_3) is a colourless, highly volatile liquid, whose vapours are flammable and explode when overheated. In combination with absorbents, methyl nitrate has been encountered as moist improvised dynamite.

Methyl nitrate dissolves in alcohol or ether but not in water. Methyl nitrate easily gelatinises nitrocellulose and evaporates very quickly from the gel.

This explosive liquid reacts by impact or friction, heating or other sources of ignition, with rapid decomposition forming large quantities of gas. Its impact sensitivity is 0.2 J, and the friction sensitivity approx. 353 N. Methyl nitrate brisance is about equal to that of nitroglycerine. Unconfined methyl nitrate coming into contact with flames in an open space may result in burning accompanied by deflagration of the vapours. Confined methyl nitrate above a certain critical diameter may react with an explosion, achieving a detonation velocity of up to 6300 m/s. In general, methyl nitrate is cap sensitive.

This liquid explosive is more often encountered in its ‘dynamite’ state, obtained by wetting an absorbent such as fine sawdust or charcoal.

WARNING. Liquid explosives should not be touched due to their toxicity and serious effects on the skin. If skin contact occurs, the area should be flushed immediately with large amounts of water. Contamination of liquid explosives with other chemicals should be avoided to prevent any unintended reactions.

5.2.4. UREA NITRATE-BASED HMEs

UREA NITRATE

Image 154. Urea nitrate
(source: Bundeswehr CBRN Defence Command ©)

Pure urea nitrate ($CH_5N_3O_4$ // $NH_2CONH_2*HNO_3$) is a white, flammable, odourless crystalline powder. Mixed with caustic potash and other liquids, it can develop a strong ammonia or urine-like odour. Because of the bonded nitric acid, it turns yellow-brown in sunlight. Urea nitrate has a highly caustic effect (it corrodes most metals) and is thermally unstable. An explosive thermal decomposition is possible if it is heated above its decomposition temperature (152°C).

Urea nitrate is very insensitive to impact and electrostatic discharge, with an impact sensitivity of 50 J and friction sensitivity of 353 N. It is hygroscopic and will dissolve in warm water (190 g/l at 20°C) and ethanol. The storability of urea nitrate is limited due to caking. Urea nitrate manufactured with a high crystallisation rate is more stable in sunlight and less hygroscopic than powder versions. The substance may react dangerously with reducing agents, powdered magnesium or other powdered metals.

Urea nitrate is used as an oxidiser. With a water content of less than 20%, it can act as an explosive on its own. However, there is no modern day commercial or military use for urea nitrate as an explosive, given its poor capacity for ageing. Pure urea nitrate is not cap sensitive. Along with most HME mixtures that contain it, it acts as a tertiary explosive and requires a booster for successful detonation.

Possible fuels used correspond to those already listed in this section. Urea nitrate HMEs will vary in colour, appearance and odour, based on the production process, fuel used, age, environmental impact (sunlight) and impurities. All these factors also affect stability and sensitivity.

OTHER UREA NITRATE–FUEL MIXTURES ENCOUNTERED:

UREA NITRATE–ALUMINIUM

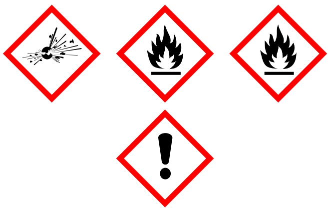


Image 155. Urea nitrate–aluminium
(source: Bundeswehr CBRN Defence Command ©)

UREA NITRATE–CHARCOAL

Image 156. Urea nitrate-charcoal
(source: Bundeswehr CBRN Defence Command ©)

UREA NITRATE–FUEL OIL

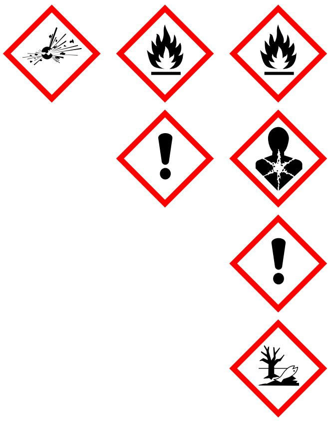


Image 157. Urea nitrate-fuel oil
(source: Bundeswehr CBRN Defence Command ©)

UREA NITRATE–MAGNESIUM

Image 158. Urea nitrate-magnesium
(source: Bundeswehr CBRN Defence Command ©)

UREA NITRATE–NITROBENZENE

Image 159. Urea nitrate-nitrobenzene
(source: Bundeswehr CBRN Defence Command ©)

UREA NITRATE–NITROMETHANE

Image 160. Urea nitrate-nitromethane
(source: Bundeswehr CBRN Defence Command ©)

UREA NITRATE–SAWDUST

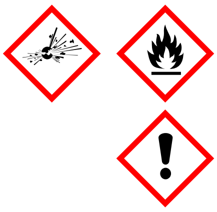


Image 161. Urea nitrate–sawdust
(source: Bundeswehr CBRN Defence Command ©)

UREA NITRATE–SUGAR

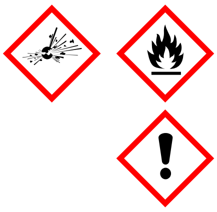


Image 162. Urea nitrate-sugar
(source: Bundeswehr CBRN Defence Command ©)

UREA NITRATE–TNT

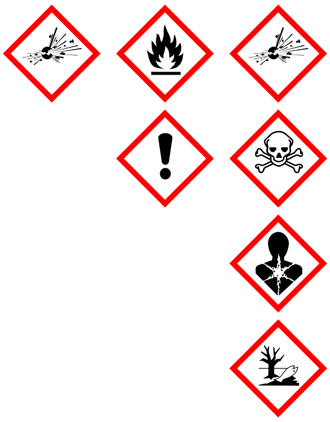


Image 163. Urea nitrate-TNT
(source: Bundeswehr CBRN Defence Command ©)

UREA NITRATE–UREA

Image 164. Urea nitrate-urea
(source: Bundeswehr CBRN Defence Command ©)

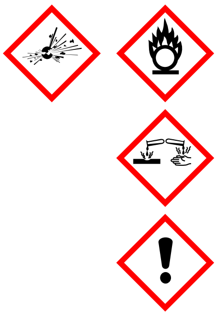
5.3. PEROXIDE-BASED HMEs

The term peroxide refers to a molecule where two oxygen atoms are tied together by a single bond. The peroxide single O-O bond is particularly weak, a characteristic which leads to the thermal instability of peroxide explosives (decomposing between 60°C and 150°C). Whilst these bonds may be weak, not all organic peroxides can be used as explosives.

Image 165. Effects of a small quantity of home-made peroxide explosive on a metal witness plate (source: BCL ©)

Peroxides are considered strong oxidisers, with high brisance, and are an extreme fire hazard when mixed with flammable materials.

5.3.1. CONCENTRATED HYDROGEN PEROXIDE (CHP)



Standard hydrogen peroxide is an aqueous solution; it spontaneously decomposes when mixed with water. Concentrations higher than 86% are hard to sustain and will decompose. Pure liquid hydrogen peroxide is not classified as a high explosive, given that it requires a relatively high input energy to be able to detonate. To form a viable HME, concentrated hydrogen peroxide can be mixed with a fuel and is therefore commonly known as a CHP HME.

The effectiveness of hydrogen peroxide-based HMEs depends on the concentration of the hydrogen peroxide and the ratio of fuel to oxidiser. As such, hydrogen peroxide is the subject of stringent regulation for both private and commercial use.

Common fuels encountered are ground spices (e.g. cumin, black pepper, chilli), flour, coffee, sugar, alcohol, glycerol and fine aluminium powder.

Image 166. Hydrogen peroxide–flour (source: Bundeswehr CBRN Defence Command ©)

Hydrogen peroxide HMEs can have a liquid, semi-liquid or pulpy appearance depending on the source materials. Their colour and odour vary depending on the fuels used. In general terms, the odour of hydrogen peroxide HMEs can be described as slightly pungent.

Image 167. Hydrogen peroxide-pepper (source: Bundeswehr CBRN Defence Command ©)

Hydrogen peroxide HMEs are generally mixed right before use; storage is not common. All these HMEs have a low chemical stability and are sensitive to heat, friction, impact and electrostatic discharge. As the concentration of hydrogen peroxide increases, so does its sensitivity. Large quantities of hydrogen peroxide HMEs may ignite due to internal auto-catalytic (or self-heating) reactions.

EXAMPLE: DISTINCTION BETWEEN ORGANIC PEROXIDE AND EXPLOSIVE MATTER CONTAINING HYDROGEN PEROXIDE

A distinction needs to be made between organic peroxides and explosive mixtures containing hydrogen peroxide. CHPs are not organic peroxides (there are no covalent bonds between the peroxide unit and organic moieties, while organic peroxides contain the organic moieties within their molecular structure) and CHPs are more akin to ANFO in terms of explosive performance. However, CHPs can be initiated without a booster. The most frequently encountered organic peroxide explosives include TATP, HMTD and MEKP.

5.3.2. ACETONE PEROXIDE

Acetone peroxide ($C_9H_{18}O_6$) or triacetone triperoxide (TATP), also known as Mother of Satan.

Image 168. Acetone peroxide
(source: Bundeswehr CBRN Defence Command ©)

TATP is a chemical compound, not a mixture. It has the properties of a primary explosive with a high detonation effect. There is no commercial or military use for TATP due to its instability.

TATP is a colourless-white crystalline or powder solid with a sugar-like appearance. It does not dissolve in water but is soluble in organic solvents. TATP that has dried after being dissolved in organic solvents is extremely hazardous to handle.

Fresh TATP has a soft acetone smell; when aged, it has a pungent, vinegar-like odour. Additives and impurities influence its physical appearance and odour.

TATP's sensitivity and stability (physical and thermal) are strongly and critically dependent on the raw materials used, with the professionalism of the manufacturing process and the HME's moisture content also playing a role. Chemical instability due to gritty impurities or acids used in production must be expected from an improvised production process. As these cannot be identified visibly, relevant HMEs should be treated as extremely unstable.

MA staff will unlikely encounter recently produced TATP. Therefore, the effects of ageing should be borne in mind. By default, TATP must be considered highly sensitive to impact, friction, electrostatic discharge and heat, like all other primary explosives. Ageing will increase its sensitivity to friction dramatically, so that even static electricity from the body or a latex glove could cause detonation. Laboratory numbers for pure, fresh TATP estimate an average impact sensitivity of 0.3 J and a friction sensitivity of 0.1 N.

HINT. It is recommended to earth oneself against electrostatic discharge to increase safety when encountering any improvised primary explosive.

NOTE. Various possible TATP–fuel mixtures exist, such as with grease, black powder or glue. This changes the appearance and colour of the HME.

TATP is highly sensitive to initiation by flame:[55]

- Small amounts of powdered TATP in a thin layer will tend to deflagrate.
- Confined crystallised TATP in thick layers will tend to detonate.

TATP presents unique hazards. It is volatile, potentially thermally unstable, vaporises spontaneously and tends to spontaneously recrystallise. (Large) crystals are more hazardous to handle than powdered TATP. Such crystals can form as TATP ages or through inappropriate synthesis and may decompose when broken.

⚠ **WARNING. Containers containing TATP should never be opened, to avoid detonation. Detonation can be caused by the rupture of TATP crystals or the friction of crystals caught within the screw threads of the container lid.**

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[55] HMTD will react similarly.

5.3.3. HEXAMETHYLENE TRIPEROXIDE DIAMINE

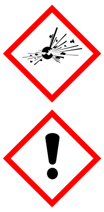

Image 169. HMTD
(source: Bundeswehr CBRN Defence Command ©)

Hexamethylene triperoxide diamine ($C_6H_{12}N_2O_6$) or HMTD, is a chemical compound, not a mixture. It has the properties of a powerful primary explosive with a high initiation effect. It has no commercial or military use, due to its sensitivity.

HMTD is a colourless and odourless fine white powder. It does not form large crystals. Because of the amines, old HMTD has a fish-like odour. It is slightly hygroscopic but does not dissolve in water or common organic solvents. It does not evaporate or recrystallise.

HMTD is very highly sensitive to heat, shock and especially friction. It is thermally unstable, will decompose in storage and is very reactive with most metals, even when dry. HMTD's impact sensitivity is 0.6 J. Its friction sensitivity is approx. 0.1 N and is considered to be similar to that of Armstrong's mixture.[56] Confined, it will detonate in small quantities. Aged HMTD loses explosive strength but its sensitivity to electrostatic discharge increases.

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[56] Armstrong's mixture is composed of potassium chlorate and red phosphorus.

5.3.4. METHYL ETHYL KETONE PEROXIDE

Image 170. MEKP
(source: Bundeswehr CBRN Defence Command ©)

Methyl ethyl ketone peroxide ($C_8H_{18}O_6$) or MEKP is a liquid chemical compound, not a mixture. It is produced using butanone / MEK, hydrogen peroxide and a catalyst. MEKP is used as a hardener for different resins. Commercially available, diluted MEKP is sensitised with phlegmatisers. Highly concentrated, it has the properties of a powerful primary explosive with a high initiation effect and its reaction can be compared to that of TATP. Confinement may cause it to explode.

MEKP is a clear, colourless, oily liquid with a pleasant odour. It is flammable and does not dissolve in water. It starts decomposing when exposed to heat between 50°C and 60°C. It is less sensitive to heat, shock and friction than TATP and can be stored. Highly concentrated MEKP is considered very reactive. It may explode upon contact with organic substances, some amines and sulphur compounds. It may react dangerously with strong bases, strong reducing agents and concentrated acids.

MEKP can cause a corrosive effect on mucous membranes and skin as well as severe eye damage (risk of blindness). If ingested, it carries the risk of severe damage to the digestive tract.

Suitable materials for storage of pure MEKP are glass (dark glass for light protection), ceramic, PVC, V2A steel[57] and rubber. Plastics must be tested regarding their resistance before use; unsuitable containers are those made of metals such as aluminium and its alloys, as well as brass, bronze, copper and its alloys, and steel.

Suitable extinguishing agents are water (spray jet), dry extinguishing powder, alcohol-resistant foam and sand.

MEKP is slightly hazardous to water supplies.

WARNING. Liquid explosives should not be touched. They must not come into contact with skin. In case this happens, the area of skin should be flushed immediately with large amounts of water. In addition, any contamination of liquid explosives with other chemicals must be avoided.

WARNING. The distinction between different organic peroxide explosives is difficult to determine with the naked eye, given the similarities in appearance of the crystalline solids. Any unidentified powder in the presence of hydrogen peroxide should be treated as HMTD in terms of extreme sensitivity. Existing render safe techniques such as kinetic disruption carry an undue risk of detonation.

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[57] V2A steel is stainless steel alloyed with chrome and nickel.

5.4. NITROMETHANE-BASED HMEs

Image 171. Nitromethane (source: BCL ©)

Nitromethane (CH_3NO_2) is the simplest organic nitro compound. It is a colourless, oily, highly flammable, polar liquid, commonly used as a solvent in a variety of industrial applications such as dry cleaning, the manufacture of pharmaceuticals, pesticides, explosives, fibres and coatings. Nitromethane is also used as a fuel additive in various motorsports and hobbies such as drag racing, and in miniature internal combustion engines for model aircraft. Nitromethane-based HMEs are used less commonly than other mixtures but were historically used by the Spanish separatist group Euskadi Ta Askatasuna (ETA). MA staff should be aware that, in general, non-state armed groups with the resources to deploy unmanned vehicles with internal combustion engines have the resources to manufacture this type of HME.

Nitromethane is not normally regarded as an explosive. However, given its oxygen balance, under certain conditions and with a strong initiator, this compound can propagate a detonation. Nitromethane was not considered a high explosive until a railroad tanker car loaded with it exploded in 1958[58] leading to two deaths and estimated damage of USD 1 million. After much testing, it was understood that nitromethane was a more energetic high explosive than TNT, although TNT has a higher brisance. Since nitromethane is oxygen deficient, some benefits have been gained by mixing it with an oxidiser in HME applications. Typical mixtures include ANNM and ANMAL (explosive mixtures of ammonium nitrate nitromethane and aluminium powder). Whilst the explosive performance of these mixtures is higher than that of ammonium nitrate–fuel oil, they are considerably more expensive to produce.

Nitromethane employed as fuel for HME mixtures can be used in a low concentration and needs no additional sensitisation. In general, it is mixed with solid oxidisers.

NOTE. Due to its tendency towards violent thermal decomposition, nitromethane and its mixture with flammable substances must not be heated or ignited in a confined space.

Nitromethane used as an oxidiser requires a concentration close to 100%. Fuels like amines, aqueous ammonia, sodium carbonate or strong acids will increase the sensitivity of a mixture. In general, these mixtures are not cap sensitive.

Used as an explosive, confined nitromethane has reached a detonation velocity of up to 6400 m/s in laboratory trials.

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[58] Interstate Commerce Commission. "Accident Near Mt. Pulaski, ILL" (PDF). *Ex Parte No 213*.

Chemical sensitisation to achieve cap sensitivity can be obtained by adding various sorts of amines / derivatives of ammonia.

Physical sensitisation is achieved by enclosing gaseous oxygen in highly concentrated nitromethane. Oxygen is introduced when substances with the physical ability to keep air pockets within their structure are soaked with nitromethane. These substances can be, for instance, fine aluminium powder, fine ground coffee, sawdust or toilet paper. This method does not retain the oxygen for long. Nonetheless, pure nitromethane or nitromethane-based HMEs will detonate when initiated by sufficient external stimuli. Based on the oxidiser to fuel ratio, confinement level and booster explosives used, the required weight of a booster charge can be small – in the range of single-digit gramme numbers.

Commercially available explosives containing nitromethane are KINEPAK® (which uses ammonium nitrate) and the high energy liquid explosive HELIX™, a binary explosive including fine aluminium powder.

Exposure to nitromethane irritates the skin and affects the central nervous system, causing nausea, dizziness and narcosis. This substance is reasonably suspected to have carcinogenic potential.

PICATINNY LIQUID EXPLOSIVE (PLX) OR MYROL

Image 172. Picatinny Liquid Explosive
(source: Bundeswehr CBRN Defence Command ©)

PLX is a high explosive composition of nitromethane 95 and ethylene diamine, with a detonation velocity greater than 6000 m/s. It is a light yellowish liquid that requires a powerful blasting cap or a booster charge. It is not considered to be friction sensitive but has an impact sensitivity above 2 J. PLX has a low chemical stability, its components are both very volatile and corrosive. PLX corrodes brass but not stainless steel.

5.5. NITRATE ESTER-BASED HMEs

Nitrate esters are an important class of explosives for commercial and military applications and are formed from the O-nitration (O-NO2) reaction of alcohols with nitric acid. The five most important nitrate esters in HME manufacture are nitroglycerine, ethylene glycol dinitrate, pentaerythritol tetranitrate, erythritol tetranitrate and nitrocellulose. Nitrate esters are highly sensitive to impact and mechanical stimuli.

NITROGLYCERINE [$C_3H_5N_3O_9$] OR NG

Image 173. Improvised nitroglycerine found in a bomb factory – discoloured from ageing (source: BCL ©)

Nitroglycerine, or glyceryl trinitrate, is probably the best known and most sensitive nitrate ester. It is manufactured on a large scale through the nitration of glycerine and is also used as a vasodilator to relieve angina pain. In its pure state it is a colourless and transparent oily liquid, with a slight sweetish smell and bitter-sweet taste. Auto-catalysation in storage is common (instead of a colourless oily liquid it may have a straw yellow or pale brown colour). This is not a problem in unconfined HME mixtures but in confinement the reaction can lead to detonation.

As a liquid explosive (freezing point 13°C), nitroglycerine demonstrates high brisance as well as the ability to provide a source of high energy in single and double base rocket propellants. At a density of 1.59 g/cm-3 its detonation velocity is 7750 m/s. It is only one of very few explosives with a positive oxygen balance, hence its use with oxygen-deficient explosives like nitrocellulose. Due to its oily liquid form, the presence of air bubbles can create hotspots leading to high sensitivity and accidental initiation during manufacture and handling. Nitroglycerine can be desensitised by mixing with absorbents such as wood pulp, flour, starch, chalk, zinc oxide or coal, and then combined with charcoal to form dynamite. Mixed with cellulose nitrate and sodium, potassium or ammonium nitrate gelatine, dynamite can also be produced.

Nitroglycerine is toxic to handle and, being a vasodilator, can lead to headaches during handling and after detonation (because of the NO_2 fumes generated). It is almost insoluble in water but soluble in most organic solvents.

Image 174. Improvised dynamite comprising nitroglycerine, potassium nitrate and charcoal (source: BCL ©)

Nitroglycerine-based dynamite has largely been replaced by ammonium nitrate-based mixtures, which are much safer to use and also less expensive.

ETHYLENE GLYCOL DINITRATE [$C_2H_4N_2O_6$] OR NITROGLYCOL, EGDN

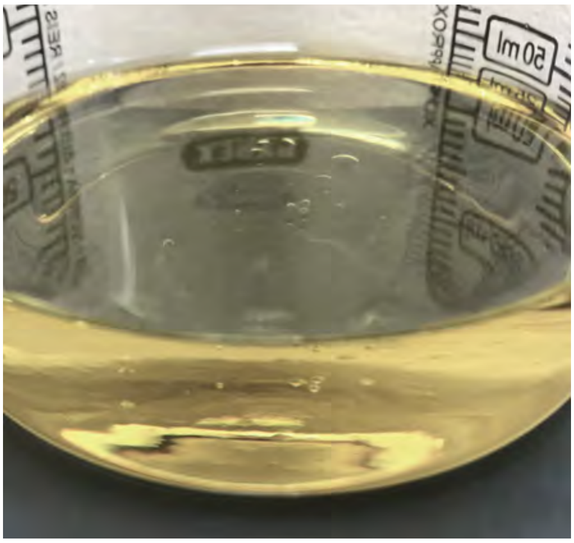


Image 175. EGDN (source: BCL ©)

EGDN or nitroglycol, is a non-hygroscopic, viscous, pale yellow-colourless oil with properties and performance similar to that of nitroglycerine. At a density of 1.49 g/cm^{-3}, its detonation velocity is 8000 m/s. EGDN has an oxygen balance of exactly 0.00 and is considered more stable than nitroglycerine against impact, although more volatile. EGDN was used in explosives manufacture to lower the freezing point of nitroglycerine, in order to produce a type of dynamite useable in colder weather (down to -22.7°C, as opposed to 13.2°C).

Due to its high vapour pressure, which does not favour use in propellant applications, it has been used as a high energetic plasticiser and taggant in plastic explosives to allow for more reliable detection. It is produced through the nitration of ethylene glycol and, like all nitrate esters, it is a vasodilator, strongly affecting blood circulation. EGDN is almost insoluble in water but soluble in most organic solvents.

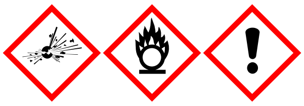
PENTAERYTHRITOL TETRANITE [$C_5H_8N_4O_{12}$] OR NITROPENTA, PETN

Image 176. PETN (source: BCL ©)

PETN is the most stable and least reactive of the explosive nitrate esters. It is an extremely powerful and brisant explosive. With a density of 1.77 g/cm^{-3} its detonation velocity is 8310 m/s. It is a fine ivory-white, crystalline solid produced through the reaction of pentaerythritol (an alcohol used in paints and varnishes) with nitric acid. Given its high detonation velocity, PETN is an easily initiated secondary explosive used in detonators, detonating cords and boosters. When mixed with an appropriate plasticiser, PETN becomes desensitised (phlegmatised) and can be moulded to almost any shape, making it hugely attractive in small improvised explosive devices. Unlike many explosives, PETN shows little trace of decomposition when stored for long periods and in high temperatures, making it a good choice for military applications (performance, reliability, safety). However, when heated above its melting point of approximately 140°C, it explodes violently (decomposition starts at > 150°C, explosion hazard > 205°C). It is insoluble in water, hardly soluble in alcohol, ether and benzene, and soluble in acetone and methyl acetate (a solvent).

The toxic effects of PETN are similar to those of nitroglycerine but less pronounced.

ERYTHRITOL TETRANITRATE [$C_4H_6N_4O_{12}$] OR ETN



ETN is another white crystalline powder, very similar to PETN in appearance and performance. It is manufactured from the nitration of erythritol. In its pure form it is extremely sensitive to shock and friction. In general, ETN is more sensitive to friction than PETN, has a positive oxygen balance and is easier to manufacture, given the wide availability of erythritol as a sweetening agent. As such, its use in improvised detonators significantly increases reliability. Its low melting point of 61.5°C suggests that it may be less adequate for long-term storage. ETN has largely replaced NG in medical applications, since its physiological effects are similar but more prolonged.

NITROCELLULOSE $[C_6H_9(NO_2)_3O_5]N$ OR FLASH PAPER, FLASH COTTON, FLASH STRING, GUN COTTON, COLLODION

Image 177. Improvised nitrocellulose (source: BCL ©)

Nitrocellulose is produced from the reaction of cellulose (obtained from cotton, wood, paper) with a mixture of nitric acid and sulphuric acid. The product normally forms a pulpy, fibrous, white, solid, granules, flakes or powder, which require vigorous washing to remove excess acid. There are different kinds of nitrocellulose, classified based on nitrogen content. Nitrocellulose's nitrogen content for explosive applications, usually (commonly) varies between 10% and 13.4%.

Nitrocellulose is highly flammable (ignites at around 180°C) and can burn even when wet. It is susceptible to initiation by percussion or electrostatic discharge. All nitrocellulose is soluble in acetone. As a projectile driver, simple gun cotton (with a nitrogen content above 13%) generates six times more gas than an equal volume of black powder and produces less smoke and heat.

Whilst nitrocellulose is proven to be a far better propellant explosive than black powder, it is susceptible to degradation in storage. Thermal stability decreases with increasing nitrate content and storage stability depends on the manufacturing process. Improvised manufacture cannot achieve the standards of industrial manufacture, and excess acid catalyses the decomposition of nitrate ester links during storage. If the temperature increases above 200°C, auto-ignition can occur.

NITROSTARCH $[(C_6H_7O_2(ONO_2)_3)N]$ OR XYLOIDINE

Image 178. Nitrostarch (source: BCL ©)

Nitrostarch was discovered in 1833 by Henri Braconnot and is produced by the nitration of corn starch with mixtures of concentrated nitric acid and sulphuric acid, followed by washing and drying. Similar to nitrocellulose, it varies in nitrogen content and was used extensively in World War I as the main explosive filling for some types of hand grenades.

Nitrostarch is a light yellow to orange-coloured powder, which resembles nitrocellulose in several aspects, other than its poor stability, relatively low strength and hygroscopicity. Unlike other nitrate esters, it is a 'headache free' explosive. Nitrostarch can be detonated when not mixed with other substances. When pressed, densities of little more than 0.9 g/cm^{-3} can be achieved.

6. GAS-GENERATING REACTIONS

Gas-generating reactions are chemical processes that produce a large amount of gas. In commercial use, a confined space is created by a pressure-resistant or pressure-responsive container. Within the container, pressure is created by a deflagrating gas-generating compound capable of undergoing self-sustaining decomposition without detonation. For safety reasons, the beginning of the reaction is controlled by means of a deflagrating ignition. Airbags are a common example of such a mechanism.

The contact of two or more specific chemicals can start a gas-generating reaction, without the need for a trigger or ignition element. Forming gas in a confined space increases the pressure to a level where the encasement / container bursts. Resulting hazards are heat, acceleration of container fragments, leakage of toxic gases, liquids or solids, that through reaction with oxygen or chemicals in their vicinity, can result in violent follow-up reactions. These reactions occur quickly and are usually unstoppable in confined spaces. In general, such effects will occur when mixing alkali or acids with metals but are not limited to this. The examples below refer to precursor chemicals commonly used to produce HMEs.

ALKALI / LYE:

Dissolved sodium hydroxide and aluminium, which produces:

- Gaseous hydrogen, an extremely flammable gas that forms explosive mixtures with air; and
- Solid sodium aluminate, a substance which reacts with and is corrosive to metals, and caustic to tissues.

ACID:

Hydrochloride acid and aluminium, which produces:

- Gaseous hydrogen; and
- Aluminium chloride, a yellow powder-like substance with a pungent, caustic odour which causes corrosive effects to mucous membranes and skin and, if inhaled, internal damage, especially to the upper respiratory tract.

Nitric acid and zinc, which produces:

- Water;
- Gaseous nitrogen dioxide,[59] which itself does not burn but increases the fire hazard on contact with flammable substances and can significantly intensify an existing fire; causes lung damage and has an irritant effect on mucous membranes; and
- Zinc nitrate, a white, odourless solid that reacts in a similar manner to nitrogen dioxide, causing localised irritation to mucous membranes and skin, chemical burns to the eyes, impairment of taste, and damage to the digestive tract including gastrointestinal disorders.

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[59] Nitrogen dioxide can ignite hydrogen / oxygen mixtures. Nitrogen dioxide is heavier than air; contact causes irritant effects and can lead to lung damage and chronic pulmonary dysfunction.

OTHERS

Calcium carbide with water forms gaseous acetylene, an extremely flammable gas that forms explosive mixtures with air.

Wood ash (sodium carbonate and potassium carbonate) dissolved in water, salt (sodium chlorate) and aluminium forms gaseous hydrogen, an extremely flammable gas that forms explosive mixtures with air and other compounds.

⚠ **WARNING. Containers containing the possible hazard of a gas-generating reaction must not be moved as this will very likely restart the reaction.**

7. IMPROVISED INCENDIARIES

This section provides information on several possible combinations, applications and hazards of improvised incendiaries and improvised chemical igniters. The main objective of this section is to raise awareness of possible applications and dangers.

Image 179. Remains of an improvised incendiary (gel-based), which has reignited when exposed to atmospheric oxygen in the disturbed ashes of a commercial property (source: BCL ©)

7.1. BASICS OF IMPROVISED INCENDIARIES

Most improvised incendiary explosives are solids, liquids or mixtures of both. They can be flammable or require chemical stimuli to start a reaction.

Some chemicals used in home-made incendiaries react violently and spontaneously when coming into contact with each other. This effect can occur accidentally or by design. Reactions are very difficult to stop once underway. Military applications of incendiary explosives include the Buck chemical fuze, used in anti-personnel and anti-vehicle mines during World War II or liquid rocket propellants. It must be noted that some of the chemicals reacting after being mixed do not require additional oxygen to combust.

The term ‘hypergolic reaction’ is used to describe the self-igniting effect between mixed liquids such as hypergolic propellants for rocket fuels. In hypergolic fuels, one liquid serves as fuel, one as oxidiser. The reaction starts immediately after mixing. Examples of oxidisers are potassium permanganate and different liquid chlorate compounds; examples of fuels are brake fluid, glycerine, ethylene glycol or propylene glycol.

Substances can even react violently when coming into contact with water, a property that can be used to start reactions deliberately. Ignition with water is used with zinc, ammonium nitrate,or ammonium chloride mixtures. Water drops, even from simple perspiration, can start the decomposition reaction.

7.2. IMPROVISED INCENDIARY COMPOSITIONS

Improvised incendiary compositions have a wide variety of applications. The use of gasoline mixed or thickened with polystyrene foam, sodium palmitate (curd soap) or oil, for example, is very common. Types of incendiary HMEs are described hereafter.

NOTE. In general, home-made incendiaries require an external heat source to combust.

Image 180. Polystyrene foam (source: Bundeswehr CBRN Defence Command ©)

THERMITE

Thermite is a solid mixture of powdered iron (III) oxide and aluminium that, after ignition, generates iron and aluminium slag in a liquid state by achieving very high temperatures, up to 2400°C. It was used commercially to weld railway rails and does not require an external oxygen source to react. Thermite cannot self-ignite and commercially produced thermite mixtures are very stable. Damp thermite may explode after ignition, although it may also not ignite at all. Sometimes the ignition of a dry mixture is delayed whilst the amount of heat to start the reaction is generated. Impurities containing copper, magnesium, sulphur or potassium permanganate can increase the hazard of an explosion or self-ignition. As such, improvised thermite can be unpredictable if exposed to heat or flame.

Image 181. Thermite
(source: Bundeswehr CBRN Defence Command ©)

GELLED FLAME FUELS

Gelled flame or paste-type flame fuels are used for incendiary devices. Gelled flame fuels adhere more readily to an object and can produce a greater heat concentration than burning gasoline. The best-known example for gelled flame fuels is napalm, but several other methods are known to make improvised gelled flame fuels.

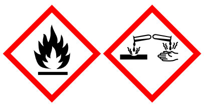
Napalm is a mixture of gasoline and various additives, including salts of naphthenic acid and palmitic acid. Napalm's oxygen source is the air; it requires an external initiation stimulus. Napalm is hard to extinguish with water as it is hydrophobic. After ignition, temperatures up to 2000°C can be reached. The adhesive effect of napalm is improved by using rubber products, soap or ethyl alcohol.

Common to improvised gelled flame fuels is the use of easily obtainable raw materials to gelatinise or plasticise gasoline or another hydrocarbon fuel. Gelled flame fuels are immiscible or hardly soluble in water. They derive the necessary oxygen from the air. The most suitable extinguishing agents are dry powder extinguishers, carbon dioxide or any means to suffocate the fire (for instance sand or fire blanket). Gelled flame fuels will continue to burn once they adhere to an object. Based on the raw chemical materials used, contact with an oxidiser or an acid may ignite gelled fuels. Known mixtures, listed by ingredient, are:

- Latex mixtures – which use gasoline, commercial or natural latex and an acid or an acid salt. Latex mixtures have the appearance of a swollen gel mass.
- Lye mixtures – which use gasoline and resin, or gasoline, tallow and alcohol to produce a flammable gel.
- Lye-alcohol mixtures – which use alcohols, which are then responsible for the gel quality.
- Soap-alcohol mixtures – which use soap (not detergents) in combination with alcohol to gelatinise gasoline.
- Wax mixtures – which use several common waxes to gelatinise gasoline.

WARNING. The presence of open flames in the vicinity of gelled flame fuels represents a serious hazard.

TRIETHYLALUMINIUM [$C_6H_{15}Al$] OR TEA



Triethylaluminium is a colourless-yellowish liquid. When thickened with polyisobutylene (binding agent) for military use, it is termed thickened pyrophoric agent (TPA). TEA / TPA can self-ignite but needs oxygen to combust that can be sourced from air or water. TEA / TPA itself cannot be extinguished with water, as it reacts explosively in contact with it. If other extinguishing agents are used, self-ignition can start again at any time through contact with air. After ignition, very high temperatures of up to 2000°C can occur.

OTHER MIXTURES

Mixtures including potassium perchlorate powdered metals, sulphur or phosphorus can also be used as incendiary explosives. These do not require an additional oxygen source. Potassium chlorate itself does not burn but reacts so violently with flammable substances that it can cause them to ignite, sometimes without a further ignition source and can considerably promote an existing fire. These mixtures require external stimuli. After ignition, temperatures of up to 2500°C can occur.

7.3. IMPROVISED CHEMICAL IGNITERS

Chemical mixtures able to self-ignite are used for igniters and fuses, meaning that they are independent from stimuli such as electricity, heat etc.[60] This offers a clear advantage from the user's point of view. With adequate coating, these igniters / fuses can function for a long time without any deterioration due to ageing. Chemical mixtures with the ability to self-ignite may be encountered as an initiation element in an explosive train as well.

To optimise the reaction, mixtures are usually contained in closed systems. The trapped heat accelerates the heat development and thus the reaction. Improvised applications separate the substances through vessels or separating discs. As a rule, this barrier between the chemicals must be destroyed by mechanical action. More sophisticated designs use acids to disintegrate these barriers. If no effect is observed after accidentally triggering an ignition element, it should not be assumed that it has failed, given that it is impossible to reliably determine the time offset for this kind of device. On the whole, the time offset is affected by age, thickness of the barrier and concentration of the dissolving agent.

WARNING. An intended delay may occur between activation of a chemical igniter and initiation.

WARNING. In general, fuses using chemical igniters do not require an initiator to be triggered. They are metal free and therefore difficult to detect.

EXAMPLE: SELF-IGNITION FUSE

The combination of a potassium–chlorate–sugar mixture with concentrated sulphuric acid is an example of an ignition mixture that is used to cause self-ignition upon impact with a target.

Fragile material containers are filled with a flammable fluid and sulphuric acid. A fabric strip (cotton) impregnated with a potassium chlorate–sugar mixture is attached to the outside of the container. On impact, the container will shatter. The reaction of the sulphuric acid with the impregnated strip will ignite the flammable fluid.

Such devices have been encountered in urban areas, stocked and ready to use. Any contact between the ignition elements must be avoided.

Devices such as these must not be considered safe to transport.

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[60] Initiation of mixtures by means of pressure, sparks, flame or electrostatic discharge is explained in section 8 *Improvised pyrotechnics*.

8. IMPROVISED PYROTECHNICS

This section provides information on several possible combinations, applications and hazards of improvised pyrotechnic HMEs. The main objective of this section is to raise awareness of possible applications and dangers.

8.1. BASICS OF IMPROVISED PYROTECHNICS

Improvised pyrotechnics are used in a similar way to industrial pyrotechnics to produce coloured lights, smoke or sound effects. Typically, pyrotechnics contain various chemicals.

As improvised pyrotechnics do not appear to have explosive properties, the hazards they pose are often underestimated. Pyrotechnics may even be considered harmless, as some are used in toys for children. However, it is important to be aware that pyrotechnics are energetic mixtures whose behaviour and stability are among the most difficult to assess, as they may be very sensitive and could produce the same effects as high explosives (depending on confinement, mixture components, impurities and the effects of ageing).

Pyrotechnic mixtures suffer greatly from ageing, which can reduce their stability and increase their sensitivity. Improvised pyrotechnics are often flame sensitive. They decompose creating high temperatures with strong gas or smoke emissions. Some mixtures can have explosive properties, especially when confined.

The raw materials used for improvised pyrotechnics correspond to the chemicals used for other HMEs.

Fuels used in improvised pyrotechnics include:

- Light metals and their alloys, such as aluminium and magnesium. Iron, zirconium and titanium can also be found;
- A source of carbon – mostly charcoal or sawdust;
- Sugars such as glucose, sucrose, lactose, mannose or fructose; and
- Various resins, sulphur, rosin, shellac, acetylsalicylic acid (e.g. Aspirin®), ascorbic acid (vitamin C) and acetaminophen (paracetamol).

Oxidisers used in improvised pyrotechnics include:

- Nitrates (potassium, sodium, barium or strontium nitrate);
- Chlorates (potassium, sodium, barium or strontium chlorate);
- Perchlorates (potassium or sodium perchlorate); and
- Manganates such as potassium permanganate.

Image 182. Fructose
(source: Bundeswehr CBRN Defence Command ©)

Image 183. Glucose
(source: Bundeswehr CBRN Defence Command ©)

Image 184. Lactose
(source: Bundeswehr CBRN Defence Command ©)

Image 185. Acetaminophen pressed as a pill
(source: Bundeswehr CBRN Defence Command ©)

Image 186. Ascorbic acid
(source: Bundeswehr CBRN Defence Command ©)

Image 187. Acetylsalicylic acid pressed as a pill
(source: Bundeswehr CBRN Defence Command ©)

8.2. NOISE AND LIGHT EFFECTS

Flash compositions can be used to produce irritating noise and light effects, for instance for stun or shock grenades used for law enforcement (so called flash bangs). Historically, flash compositions called flash powders were used to create flashes for photography. Today, they are used in pyrotechnics for theatres, in firecrackers and military training aids. Flash compositions are mixtures of oxidisers and fuels. They burn very rapidly and may decompose violently when confined. Some compositions are very powerful and can produce a blast effect similar to TNT, depending on quantity and confinement.

Flash compositions are very sensitive to all external stimuli, including static electricity. The (intended) presence of sulphur and a small particle size of constituents increases their sensitivity. Magnesium particles do not need to be as small as aluminium particles to achieve the same negative impact or sensitivity.

Hazards of flash compositions:

- Flash compositions containing magnesium are more sensitive than other mixtures containing aluminium. Magnesium mixtures coming into contact with PTFE will ignite spontaneously.
- Mixtures containing chlorates. One component decomposes faster than those with perchlorates and are more sensitive. In general, chlorates or perchlorates mixed with sulphur / sulphide are sensitive to vibration, friction and sparks.
- Mixtures including potassium permanganate, barium oxide or barium chlorate as they are not stable and tend to decompose spontaneously.

Flash compositions encountered in the past included potassium nitrate, potassium perchlorate, strontium nitrate or barium nitrate as oxidiser, and fine powdered metal aluminium or magnesium, sometimes sulphur and charcoal as fuel. The composition ratio of all these mixtures is different. Based on trials using raw materials with a defined particle size and mixture, the impact sensitivity of nine tested combinations differed from 2.9 J to 17.7 J. Apart from Armstrong's mixture and under laboratory conditions, barium nitrate-based flash compositions were more sensitive to impact and friction than those with potassium nitrate. Potassium perchlorate compositions demonstrated a very high friction sensitivity down to 32 N.

NOTE. Flash compositions must be considered very reactive, sensitive and unstable. Contamination or further mixing with other chemicals must be prevented. Precautions against electrostatic discharge must be taken.

8.3. COLOUR EFFECTS

Pyrotechnics can be used to create colour effects, such as to dazzle the crew of vehicles or to mark positions. The duration and intensity of these effects depend on the chemicals used. In general, the pyrotechnic basic mixture for coloured lights includes potassium perchlorate, a carbon source and sulphur.

Various chemicals combust with a unique colour spectrum.[61] This can be used to identify chemicals in a mixture and may allow for an estimation of its hazards. The list below is not exhaustive.

• Blue:	copper salts	azure
	arsenic, lead, selenium	light blue
	cobalt	deep blue
• Orange:	sodium salts	yellow
• Red:	strontium salts	deep red
	calcium compounds	orange
	lithium	crimson
• Green:	barium salts	light green
	copper	green
	zinc	green
• Violet:	potassium components, potassium perchlorate	violet
	caesium components	violet
• Gold:	iron	gold
	coal	gold

Image 188. Lithium, an alkali metal
(source: Bundeswehr CBRN Defence Command ©)

Coloured effects are brightened by including aluminium, magnesium or zirconium and intensified by adding mercuric chloride. Adding powdered metals increases sensitivity.

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[61] As a prerequisite for their use in pyrotechnics, the compounds must be volatile at flame temperature.

8.4. SMOKE EFFECTS

Saccharose (sucrose), potassium nitrate, as well as sulphur, carbon tetrachloride and charcoal are the basic components for smoke effects. Iron oxide, metal powders and black powder are encountered in white smoke screen mixtures and black smoke mixtures. Smoke can be coloured by adding a colouring agent.

Smoke effects are created by burning potassium nitrate and magnesium mixtures or via the reaction of oxygen with white phosphorus or with hexachloroethane compositions. Achievable expansion and duration of smoke effects depend on the amount of chemicals used, and weather conditions.

WARNING. It is important to be aware that smoke poses a health hazard. Inhalation can result in severe poisoning and lung damage.

9. IMPROVISED PRIMARY EXPLOSIVES

This section provides information on several possible combinations, applications and hazards of improvised primary explosives. The main objective of this section is to raise awareness of possible applications and dangers.

9.1. BASICS OF IMPROVISED PRIMARY EXPLOSIVES

Primary or initiating explosives are used to commence deflagration or detonation. Initiators include blasting caps, detonators and detonating cord. In general, blasting caps are mechanically or electrically initiated. Improvised igniters are manufactured as well. Their application includes the ignition of propellants or incendiary charges.

Improvised primary explosives encountered are TATP, HMTD and lead azide. Each of these can be initiated by flame or friction. TATP and HMTD can be used as main charge compositions as well. Improvised blasting caps can contain more than one explosive composition, such as potassium chlorate or sugar combined with TATP, PETN and ETN for instance.

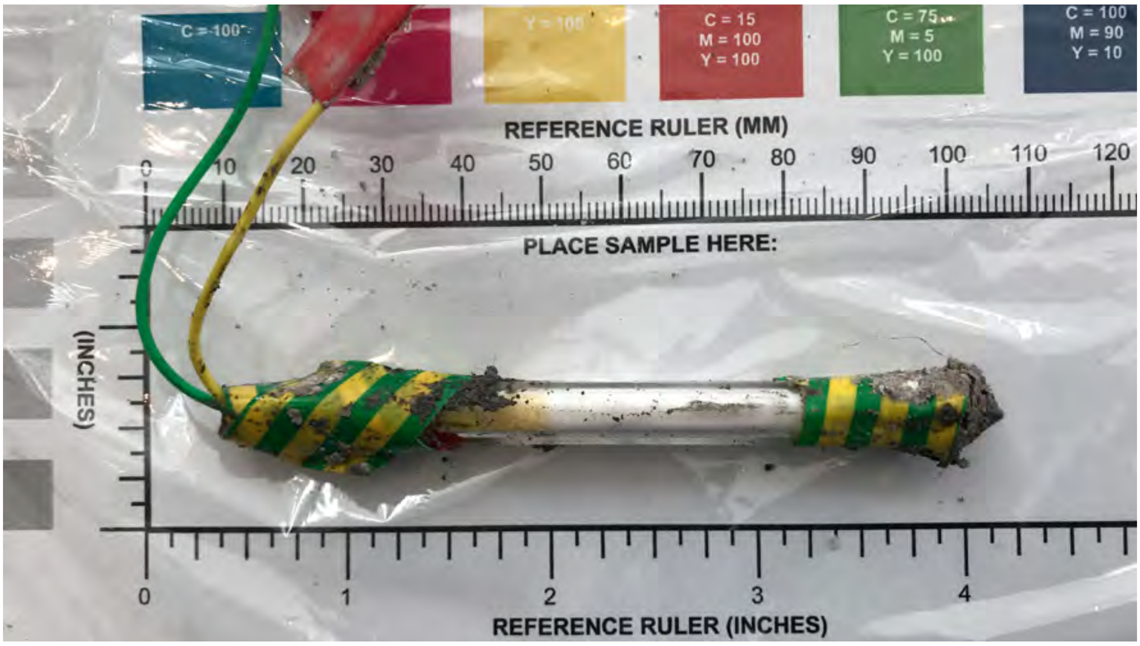


Image 189. Electrically initiated detonator using improvised chlorate and organic peroxide explosives (source: BCL ©)

The design of an improvised detonator very much depends on available resources and the producer's knowledge. Usually, improvised detonators encountered are electrically initiated (e.g. by a blasting machine, a battery or another source of electricity). A second common type is with a mechanically initiated improvised blasting cap (initiated by a safety fuse or by a shock tube system, for instance).

Improvised detonators with no metal content have also been encountered. In these cases, paper or plastic was used for the casing. Furthermore, if the presence of a detonator is not indicated caution should be taken, as various non-metal ignition techniques have been developed. For example, some TATP compositions have been mixed with ground glass to be able to detonate by friction alone.

Image 190. Improvised rocket igniter (source: FSD ©)

Further initiation elements retrieved housed two separated chemical compounds that would violently react when combined. These initiate through the energy released when the components are mixed. Such improvised initiation elements often contain no metal, which complicates detection.

WARNING. In aged, improvised detonators, explosive fillers may react with the metal casing, potentially resulting in the formation of extremely sensitive metal salts. Therefore, improvised detonators should NOT be considered safe to transport under any circumstance.

Image 191. Example of an improvised detonator (source: FSD ©)

WARNING. Improvised detonators are hazardous. Analysis, disassembly or handling of improvised detonators should not be conducted by untrained personnel.

Home-made primary explosives display characteristics that make their handling extremely dangerous, such as their high sensitivity and adverse mechanical properties. Many detonator compositions used in some improvised explosives (such as silver azide) have been discounted from any form of military or industrial use because of their overwhelming negative properties such as lack of stability, for instance.

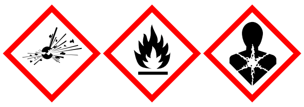
WARNING. Improvised primary explosives and improvised explosive devices containing home-made primary explosives should not be considered safe to transport.

HINT. Improvised detonators, like primary explosives, should be considered very sensitive to heat, flame, impact and electrostatic discharge. When encountering improvised primary explosives, confirmed or suspected, all possible measures (technical and organisational) must be taken to avoid initiation by one of these triggers.

Typical substances encountered in the production of improvised primary explosives include acetone, acetic acid, aminoguanidine carbonate, ammonia, dry fuel, hydrogen peroxide, iodine, mercury, nitric acid, picric acid, potassium chlorate, silver nitrate, sodium azide, sodium hydroxide, sodium nitrate, sulphur or sulphuric acid.

9.2. EXAMPLES OF IMPROVISED PRIMARY EXPLOSIVES

DINITROBENZENEDIAZOXIDE [$C_6H_2N_4O_5$] OR DIAZODINITROPHENOL, DINOL®, DDNP



DDNP is an explosive, yellow, crystalline powder that is neither hygroscopic nor volatile. It was used as a starting material for dyes until its explosive properties were discovered by Wilhelm Will of the Prussian Ministry of War, in 1892. Subsequently, it was used as an initiator for explosives where lead-free priming compositions were required. However, its military use ceased because of its poor physical properties.

When exposed to sun and / or light, it will darken to a dark red-brown colour and have a slightly reduced performance. Industrially produced DDNP is shipped wet with at least 40% water or as a water-denatured alcohol mixture. Confined DDNP can explode under prolonged exposure to heat or fire. It can be initiated by static discharge, which makes handling difficult. Its detonation velocity is approx. 4400-6900 m/s and varies depending on density and confinement. The decomposition temperature of DDNP is between 165°C and 195°C. Its friction sensitivity is considered to be less than that of mercury fulminate, TATP and lead azide. DDNP's impact sensitivity is approx. 1.5 J. Its fumes are toxic and caustic.

LEAD AZIDE $[Pb(N_3)_2]$

Image 192. Lead azide powder (source: BCL ©)

Image 193. Lead azide, produced by a very fast reaction that has caused small crystals to form visible chunks. The pinkish tint is uncommon
(source: Bundeswehr CBRN Defence Command ©)

Lead azide is an explosive, colourless, crystalline solid that appears as light-greyish needles or white powder. It explodes at between 315°C and 360°C and does not dissolve in water. Lead azide is resistant to heat and humidity. Its sensitivity increases with the size of the crystals. Pure lead azide has an impact sensitivity of 2.5–4 J and a friction sensitivity of 0.1–1 N. Depending on its density, the detonation velocity is between 4630 m/s and 5180 m/s. Lead azide reacts by impact or friction, flame or other sources of ignition with rapid decomposition and forms large quantities of gas. Lead azide reacts with copper, zinc, cadmium or alloys containing these metals forming other azides. As such, the choice of storage medium and confinement vessel is important.

Lead azide is less toxic than sodium azide. Its toxicity is due to the azide ion, which can cause lowered blood pressure, vertigo, nausea and collapse. Lead azide can cause damage to the kidneys, spleen and induce fatal convulsions.

Lead azide is highly hazardous to water supplies, even in small quantities. Leakage into water, sewerage systems or soil must be prevented.

LEAD STYPHNATE [$C_6HN_3O_8Pb$] OR TRICINAT, KNALLQUECKSILBER

Image 194. Lead styphnate (source: BCL ©)

Lead styphnate is an explosive, crystalline solid that has an orange-yellow to dark brown colour. It is not hygroscopic, is insoluble in water and sparingly soluble in acetone. Lead styphnate (particularly in long thin crystals) is particularly sensitive to flame and electric sparks and does not react with metals. In general, it reacts by impact or friction, heating or other sources of ignition with rapid decomposition, forming large quantities of gas. The impact sensitivity of lead styphnate is 2.5–5 J, the friction sensitivity is approx. 1.5 N. Lead styphnate is very sensitive to electrostatic discharge. It explodes at 260°C. Depending on its density, the detonation velocity can reach up to 5200 m/s.

Lead styphnate is highly hazardous to water supplies, even in small quantities. Leakage into water, sewerage systems or soil must be prevented.

MERCURY (II) FULMINATE [$Hg(CNO)_2$] OR MERCURIC CYANATE, MERCURY DIFULMINATE

Image 195. Mercury fulminate (wet)
(source: Bundeswehr CBRN Defence Command ©)

Mercury fulminate is an explosive, pale yellow to white-grey, crystalline solid that is insoluble in water. When dry, it is highly sensitive to shock, impact and friction. It will respond to other external stimuli, for instance sparks and flame, with a rapid decomposition and the formation of large quantities of gas. Mercury fulminate’s impact sensitivity is 1–2 J only, its detonation velocity can reach up to 5000 m/s, depending on the density. It is considered extremely sensitive to friction. Due to its sensitivity (greater than that of lead azide), it is often stored in water and dried prior to use. Its fumes contain toxic mercury. Mercury fulminate is reported to be relatively safe to handle when wet.

An explosion may occur when mercury fulminate comes into contact with sulfuric acid.

Mercury fulminate is highly hazardous to water supplies, even in small quantities. Leakage into water, sewerage systems or soil must be prevented.

NITROGEN TRIIODIDE [NI_3]

Image 196. Nitrogen triiodide (wet)
(source: Bundeswehr CBRN Defence Command ©)

Nitrogen triiodide is an explosive, black, extremely unstable, crystalline powder. It explodes under the slightest touch or warm heating. Dry, it is nearly uncontrollably sensitive. Because of its sensitivity, nitrogen triiodide is not considered to be practical for improvised explosive use.

SILVER ACETYLIDE [Ag_2C_2]

Image 197. Silver acetylide
(source: Bundeswehr CBRN Defence Command ©)

Silver acetylide is an explosive, white, crystalline solid that is insoluble in water. It is very sensitive to impact; its flashpoint is around 77°C. Its impact sensitivity is less than 1 J, its friction sensitivity is 0.1 N. Because of its tendency to decompose during storage and sensitivity, it has no commercial applications.

SILVER AZIDE [AgN_3]

Image 198. Silver azide
(source: Bundeswehr CBRN Defence Command ©)

Silver azide is an explosive, colourless solid in the shape of crystal needles (forming the chunks shown in Image 198). It will darken when exposed to light. It is sensitive to heat, friction and impact and does not dissolve in water. Its detonation velocity is 1000-5000 m/s, depending on its density and charge geometry. It starts to decompose at 270°C and, heated quickly to 300°C, it will detonate. Silver azide is no longer in commercial use because of its high manufacturing cost and very high friction sensitivity.

It is highly unlikely that MA staff will come across silver azide given its tendency for such spontaneous detonation.

SODIUM AZIDE [NaN_3] OR SODIUM AZOIMIDE, SODIUM TRINITRIDE, SMITE

Image 199. Sodium azide
(source: Bundeswehr CBRN Defence Command ©)

Sodium azide has been used in airbags with an oxidiser to create a gas-generating reaction. It is also used in the chemical industry as a reactant. Even though it does not own the properties of a primary explosive, it can be encountered by MA staff as it is used to produce other azides, such as lead azide. Sodium azide is a combustible, crystalline, white, colourless solid. It is highly soluble in water and sensitive to moisture. Its flashpoint is approx. 300°C. It can cause dust explosions.

Sodium azide must not come into contact with non-ferrous metals, as this leads to the formation of metal azides that are sensitive to impact and friction. In case storage containers are required, suitable materials are glass, stainless steel or plastic.

Sodium azide is considered very toxic, causing irritation to mucous membranes and skin, functional disorders of the central nervous system and cardiovascular system, as well as metabolic changes.

Sodium azide poses severe hazards to water supplies. Leakage into water, drainage and sewerage systems or the ground must be avoided.

TETRA AMINE COPPER (II) CHLORATE [$Cu(NH_3)_4(ClO_3)_2$] OR CHERTIER'S COPPER, TACC

TACC is a shock- and flame-sensitive solid, improvised primary explosive. It will decompose on impact.

TETRAZENE [$C_2H_8N_{10}O$] OR 1-TETRACENE

Tetrazene is an explosive, colourless-light yellow, crystalline solid with a downy appearance. It does not dissolve in water, alcohol, ether or benzol. Its effectiveness to initiate is considered low but tetrazene can be used in detonators when initiated by another primary explosive functioning as an intermediate booster. When mixed with another primary explosive, it increases the latter's sensitivity to flame or heat. Tetrazene starts to deflagrate at 140°C and its impact sensitivity is approximately 1 J.

Tetrazene can cause eye irritation and is harmful if inhaled or swallowed. Inhalation of high concentrations may cause difficulty in breathing. Ingestion may cause nausea, vomiting, constipation, cramps and stomach discomfort.

10. GENERAL SAFETY CONSIDERATIONS

This section provides an overview of general safety considerations when encountering HMEs, abandoned chemicals (for example, in former industrially used storage sites), abandoned manufacturing sites or ammunition stockpiles during mine action (MA) operations.

The aim is not to reiterate well-established standards for safeguarding staff from explosive hazards as these are comprehensively covered by International Mine Action Standards (IMAS), International Ammunition Technical Guidelines (IATG), national mine action standards, as well as standing operating procedures (SOPs). Rather, this section focuses on options to counter the health risks that HMEs or chemicals pose to MA staff.

WARNING. For many chemicals and biological hazards (e.g. substances produced by the decay of organic matter), required safety measures to prevent acute or chronic damage to the human body, organic life or the environment are very specific and unique.

Substance databases and safety data sheets are a recommended source for comprehensive information required when encountering chemicals. Safety data sheets include details on personal protective equipment (PPE) required when handling a specific chemical. If the type of chemicals likely to be encountered is known, safety data sheets should be used to define required PPE when preparing a specific task. In general, an organisation's SOPs should cover safety guidelines when encountering unknown chemical, yet non-explosive, threats.

10.1. BASIC SAFETY RULES AND CONSIDERATIONS

This sub-section describes basic safety rules and considerations concerning the non-explosive hazards of HMEs and / or their precursors.

10.1.1. SAFETY CONSIDERATIONS

HMEs or their precursors do not only expose personnel to explosive hazards. Some substances or compounds used in their manufacture are physically sensitive, others are highly corrosive, carcinogenic or toxic. Exposure may cause short-term effects, such as skin irritation, or lead to more serious long-term health issues, such as cancer, as in the case of nitrobenzene, for instance. Furthermore, absorption, inhalation or ingestion of a few milligrammes or less of certain chemicals can be lethal to humans.

WARNING. Absorption can occur via respiration, mucous membranes, skin or the digestive system. Protection measures to counter all (four) ways of absorption must be implemented.

Good practices applied in order to counter hazards posed by HMEs and chemicals are diverse; some may be implemented on a selective basis only. In general, interaction with HMEs and chemicals should only take place when the appropriate safety measures are in place. Personnel should be trained in the appropriate skills to handle hazardous material. These skills must include first aid procedures and using first aid equipment, as required, when addressing anticipated cases of contamination.

Safety considerations should not only cover personnel, but also environmental protection and measures to ensure public safety from non-explosive hazards as well. Disposal techniques and procedures must be tailored to the specific HMEs / chemicals.

GOOD PRACTICE. Environmental response may include clean-ups from hazardous materials and their remnants.

Image 200. Finding of chemicals contaminating the environment. An exposure to dust and / or particles is likely; an absorption can occur via respiration, mucous membranes, skin or digestive system. An assessment of the chemical's hazards aids in selecting appropriate PPE and measures to minimise the impact on the environment (source: FSD ©)

All flame- or spark-producing devices should be kept away from HMEs or their precursor chemicals. Equipment and clothing which does not create static electricity should be used, as electrostatic discharge can trigger improvised explosives. In non-contaminated areas, cotton clothing and shoes with rubber soles are recommended. Equipment must meet explosion-proof standards. The movement of personnel (walking) or remote means (tracks or wheels) should not result in unnecessary pressure being applied to HMEs or their precursors.

WARNING. An HME should always be considered as highly sensitive, energetic matter.

When encountering packages or canisters, additional research as well as technical support may be required before being able to identify hazards. Packaging and casings are sometimes used without markings, are wrongly labelled or reused. It is important to understand the local supply chain and to know names and labels used locally / regionally for common precursors.

NOTE. Explosive trains including a mix of commercial, military and HMEs that cannot be separated should be considered as an HME in its entirety.

Image 201. Green packaging for chemicals reused as main charges, prior to disposal (source: FSD ©)

HMEs and chemicals must not be mixed. Substances may react dangerously or explode when in contact with each other. Chemicals and HMEs must be positively identified prior to further processing. It is recommended to treat unknown bulk explosives / chemicals as if they were HMEs until positive identification has been carried out.

Groups of chemicals that may react when coming into contact with each other, and the possible resulting hazards are listed in Table 12:

CHEMICAL SUBSTANCE		HAZARD
Acids	Metals	Spontaneous combustion
Acids	Alkalis	Exothermic reaction (release of heat)
Oxidiser	Organic substances	Fire, explosion
Sulphides	Acids	Toxic, hydrogen sulphide
Alkali metals	Water	Spontaneous combustion
Carbides	Water	Highly flammable, formation of acetylene gas
Metal powder	Aqueous solutions	Spontaneous combustion
Metal powder	Air / oxygen	Spontaneous combustion
Nitric acid	Organic substances	Toxic, hydrogen sulphide
Nitric acid	Metals	Toxic, hydrogen sulphide

Table 12. Overview of possible dangerous interactions between chemicals

Measures to prevent an accidental release of chemicals as well as to prevent fires must be implemented. These measures may vary based on the source of the hazard or its toxicity. The default, pre-planned minimum measures should include:

- Marking and clearing the endangered area and warning the local population of the area affected;
- Entering a contaminated area only with suitable protective equipment;
- Ensuring that a universal binder (absorbent and neutralising agent for spilled acids) is available. Binding agents and cleaning agents should be disposed of in accordance with environmental protection regulations;
- If a release of chemicals occurs within an enclosed infrastructure, ensuring that rooms are ventilated, and contaminated objects and floors cleaned.

10.1.2. WORK HYGIENE AND SAFETY

To minimise the exposure to toxic elements, the regulations used in industries dealing with chemical agents should be applied when encountering HMEs and / or precursor chemicals. Personal hygiene rules should be followed very strictly.

Regulations used by industries include:

- Items known as contraband (e.g. food and drink, matches or drugs) are not allowed inside contaminated areas and working areas.[62] Suitable areas must be set up for this purpose.
- Avoiding contact of chemicals with skin. Skin cleaning is required in case of contact with a chemical.
- Preventing inhalation of vapours or aerosols.
- Limiting contact with clothing / PPE. Contaminated clothing must be changed and cleaned thoroughly. It is important to be aware that, for some chemicals, cleaning should not be done using water. If PPE is used, PPE should not be oversized or loose, it must fit. For the application of some PPE, training is required.
- Changing work clothing before rest breaks, if contaminated.
- Separate storage facilities must be available for street and work clothing, if there is a risk of contamination of work clothing.
- Cleaning skin with soap and water before breaks and at the end of work.

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[62] A list of what constitutes contraband can be found in IATG 06.10 clause 5.3, and Annex C.

10.2. PERSONAL PROTECTIVE EQUIPMENT AND INTRINSICALLY SAFE EQUIPMENT

The use of PPE is well described and regulated within the MA sector. This sub-section's objective is to describe basic PPE considerations to counter **non-explosive, toxic** and **caustic hazards** from HMEs or raw materials as well as biological agents, such as those transmitted by corpses.

10.2.1. APPLICATION OF PPE AND INTRINSICALLY SAFE EQUIPMENT

PPE is equipment and clothing that is intended to be worn or kept by employees at work and which protects them against one or more safety and health risk.[63]

PPE designed to counter chemical, biological or other hazards can be quite specific. Masks and respirators might be included in a PPE kit as well. Working in contaminated or confined spaces may increase the level of PPE needed; for instance, to counter absorption via inhalation.

PPE designed to counter non-explosive, toxic or caustic hazards, can be purchased via providers specialised in environmental protection, via suppliers for the chemical industry or via online shops.

Images 202 and 203 demonstrate situations where MA personnel can be exposed to non-explosive, toxic or caustic hazards, in addition to explosive hazards, by chemicals or by containers with unknown content.

Image 202. Substance presenting a possible exposure to ammonium nitrate. Unprotected, the ammonium nitrate may be absorbed via breathing or via the skin. Ammonium nitrate dust stirred up by the wind can irritate eyes, mucous membranes or the respiratory system (source: GICHD ©)

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[63] IMAS 04.10 Glossary of mine action terms, definitions and abbreviations, Second edition, Amendment 10, February 2019.

Image 203. Finding of various canisters and barrels with unknown content next to a former textile factory in Mosul, Iraq; located by an explosive detection dog (source: GICHD ©)

An assessment of a planned task can support the choice of PPE, for instance regarding the required level of protection against chemicals or the use of disposable or reusable PPE. This assessment may include the following questions:

- What activities are being carried out?
- What work procedures are being used?
- Which hazardous substances / biological agents are expected?
- What quantity of hazardous substances / biological agents is expected?
- In which physical state or in which form does the hazardous substance / biological agent occur?
- To what extent or in what form is there contact with the hazardous substance / biological agent?
- How long and how intensive is the contact with the hazardous substance / biological agent?
- Is the PPE exposed to mechanical stress?
- Are there possibilities for storage and cleaning of used PPE?
- Are there possibilities for decontaminating of used PPE?
- Are there possibilities for proper disposal of used PPE?

PPE must not expose MA staff to additional risks, for instance by blocking their field of vision or by severely hampering mobility when conducting survey, search, clearance or disposal.

NOTE. Use of specific PPE may require additional training.

HINT. PPE should never be more restrictive than necessary.

⚠ **WARNING. For all elements of PPE, prescribed time limitations of exposure to chemicals (leading to the permeation of PPE) must be observed; if this limitation is reached after contact with the relevant substances, the protective clothing must be replaced immediately.**

⚠ **GOOD PRACTICE.**

PPE should be available for first responders to ensure their safety in case of an emergency.

PPE should be cleaned daily, after use. It may be necessary to use specific types of PPE while cleaning contaminated PPE. Only decontaminated equipment and PPE should be used, particularly when working in different areas contaminated with different chemical hazards.

Maintenance work on PPE should only be conducted by certified personnel.

It is recommended that used PPE is kept separate from new unused equipment, even after cleaning and decontamination.

10.2.2. CONSIDERATIONS REGARDING SPECIFIC PPE

Hereafter, explanations of PPE that protects the torso, head and limbs, the respiratory system, the eyes, and the hands from non-explosive, toxic and / or caustic hazards, are provided.

PPE FOR BODY PROTECTION (HAZARDOUS MATERIAL SUITS)

Body protection is necessary to prevent direct exposure of body tissue and external organs to a hazard, such as a toxic hazard, for instance. It supports the prevention of a chemical's absorption through the skin and / or mucous membranes. Body protection, such as chemical protective suits, can be combined with a mask, gloves or boots to achieve the required protection level.

Appropriate body protection with regard to chemical-related hazards covers a wide range of equipment, from an apron up to chemical protection suits, which must be tailored to the hazard and the size of the person using it.

As with all PPE, chemical protective suits are tested according to relevant (national) standards and their respective requirements regarding dust, gas and liquids. Amongst other effects, they are tested for abrasion resistance, puncture resistance, tear resistance, tensile strength and resistance to the permeation of chemicals. A distinction is made between different types, as follows:

- Gas-tight chemical protective suit, including:
    - Gas-tight chemical protective suit with an ambient air independent breathing air supply worn in the suit;
    - Gas-tight chemical protective suit with an ambient air independent breathing air supply worn outside the suit;
    - Gas-tight chemical protective suit with overpressure breathing air supply;
- Non-gas-tight chemical protective suit;
- Protective clothing against liquid chemicals (liquid-tight);
- Protective clothing against liquid chemicals (spray-tight);
- Protective clothing against (fine and / or dispersed) particles of solid chemicals;
- Spray-tight protective clothing (time limited).

Chemical protective suits can combine protection from hazards from liquids and from sprayed and solid chemicals, for instance. Furthermore, PPE with antistatic properties, or protective clothing against infectious agents or biological hazards, is also available.

WARNING. The effectiveness of PPE with antistatic properties depends on air humidity.

HINT. If PPE with antistatic properties is certified according to the European Norm 1149-5, the functionality of the antistatic equipment is only guaranteed for a humidity level greater than 25%.

The maximum time before a hazardous chemical breach a protective garment or liner (time limit of resistance, permeation by the chemical), resulting in the PPE losing its protection, should be known and taken into consideration when carrying out tasks. These data are provided by PPE manufacturers and are based on both the acting chemical and material used.

Even though maintenance and repair of chemical protective clothing is carried out by trained personnel, chemical protective suits should be inspected for defective fasteners, holes or cracks before use. This applies to both disposable and reusable protective clothing. Even new, unused chemical protective clothing may have been damaged by careless opening of packages. Therefore, a visual inspection should be carried out before wearing unused protective clothing for the first time.

The use of flame-retardant underwear / clothing can be appropriate to minimise the heat effects of combustion, deflagration or detonation to the human body.

PPE FOR RESPIRATORY PROTECTION

Respiratory protection aims to prevent absorption via mucous membranes and lungs.

Filters and masks must be tailored to counter specific contaminating substances. To ensure this, the type and characteristics of the contamination must be known. MA staff should be informed about the protective properties of filters and how they are specified (for instance markings and labelling), restrictions of respiratory protection equipment, and the range of use of this equipment.

Gas filters must only be used against contaminants such as gases and vapours, whilst particle filters are used to counter particle contaminants. If contamination with gases and particles is expected, combination filters or combined filter systems should be employed.

It may be necessary to use a rebreather in case of an emergency such as an unintentional substance release or if concentration limits are exceeded. Such equipment may also be needed if the oxygen concentration of inhaled air is below a certain level (17%).

PPE FOR EYE PROTECTION

Different kinds of glasses and eye protection are available. Appropriate eye protection must be worn, one that is resistant to a chemical's corrosive effects, for instance. If the face is also at risk, an additional protective screen must be used.

In case of eye-damaging vapours or aerosols, a full-face mask should be worn.

PPE FOR HAND PROTECTION

In general, protective gloves should be used. The gloves' material must be sufficiently impermeable and resistant to the substance expected to be found. Gloves should be obtained from a certified manufacturer.

Gloves should be checked for leakage before use. If contaminated, they should be pre-cleaned before removing and being disposed of. Reusable gloves should be stored in a well-ventilated location.

The maximum time before a hazardous chemical breach a glove, resulting in the glove losing its protection, should be known and taken into consideration when carrying out any task. For instance, natural rubber gloves are breached by acetone within 10 minutes.

WARNING. In the case of some substances, such as peroxides or acids, fabric or leather gloves are completely unsuitable. For instance, cotton or Nomex® gloves are unsuitable for handling spilled nitric acid or sulphuric acid, leather gloves are unsuitable when handling hydrogen peroxide (of unknown concentration).

For gloves, the time limitations of resistance given by a manufacturer are standard values based on a temperature of 22°C and permanent contact with the hazard. Increased temperatures and wearing time reduce the breakthrough time.

In case of doubt, the manufacturer should be contacted. If a glove's thickness is approx. 1.5 times thicker / smaller than the equivalent model for which the information is given, the respective breakthrough time is doubled / halved respectively. Hazard data only applies to pure substances. When transferred to a mixture of substances, the data should only be considered as a guideline.

10.3. TEMPORARY STORAGE OF HMEs AND CHEMICALS

Storage and transport of ammunition, explosives and energetic materials are well regulated. Robust SOPs and solutions have been developed regarding the storage and transport of hazardous goods. This sub-section illustrates some good practices for the temporary storage of HMEs and chemicals, designed to prevent hazardous accidents due to poor storage conditions.

The International Technical Ammunition Guidelines (IATG) deliver high-quality support for adequate ammunition management. Much of the advice provided by the IATG are of significant use when forced to store HMEs and chemical precursors.

The United Nations 'Recommendations on the Transport of Dangerous Goods' addresses the regulation of the transport of dangerous goods, in relation to governments and international organisations. The recommendations have been developed in the light of technical progress, the advent of new substances and materials, the demands of modern transport systems and, above all, the requirement to ensure the safety of people, property and the environment.

NOTE. For the purposes of this publication, *temporary storage* is defined as the storing of hazardous substances in closed containers or packages in a facility designated for this purpose. *Storage* is considered as the storing of hazardous goods in facilities developed for this purpose, as found in industry or waste management facilities.

HINT. Comprehensive information on the transport of ammunition and hazardous goods can be found in the United Nations 'Recommendations on the Transport of Dangerous Goods', the 'Accord européen relatif au transport international des marchandises dangereuses par route' (ADR), and the European Union's agreement concerning the international carriage of dangerous goods by road. IATG 08.10 Annex D provides a summary of these regulations.

10.3.1. GENERAL CONSIDERATIONS ON TEMPORARY STORAGE OF HMEs AND CHEMICALS

The storage of explosives and chemicals is regulated by domestic law. Similar laws and obligations will regulate temporary storage. Generally, normative frameworks on the storage of hazardous substances (solid, liquid and gaseous) are developed to regulate their storage in their original containers (for instance drums, bottles or bags). Such frameworks can be very complex and cover a wide variety of substances, distinguishing between explosive properties and other hazards. Even though the legal requirements for storing hazardous substances may vary across countries and can be complex, many regulations offer tangible guidelines. MA organisations should assess any hazards as part of their risk assessment and take appropriate protective measures.

Encountering HME and chemicals should be identified as a risk during early planning phases. Priority should be given to their immediate disposal or storage in a waste management facility.

GOOD PRACTICE. Being already mixed as an explosive, an HME's threat is an explosive one. The IATG cover good storage principles and practice. An HME should always be stored using regulations for compatibility group 'L', including when storage conditions have been taken into consideration and the HME is safe to transport. An HME should always be stored separately from all articles belonging to other compatibility groups, as well as from all other articles of different types of compatibility group and hazard division 1.1 (hazard division 1.1 refers to substances and articles which have a mass explosion hazard).

The decision to provide temporary storage very much depends on an organisation's mandate, regional situation and other conditions such as access to waste management facilities. However, short-term storage of HMEs and chemicals requires minimum standards for storage and safety as well. Requirements to be considered when temporarily storing collected chemicals and HMEs should include:

- Preventing further contamination of the environment;
- Protecting stored materials from weather and other external influences;
- Securing against unauthorised access to HMEs and chemicals;
- Securing of the storage site against unauthorised entry; and
- Complying with necessary safety measures when handling hazardous substances.

Some professional waste management facilities (not all of them) are equipped with appropriate means to store and process chemicals; indeed, there may be companies specialised in the management of chemical waste. Depending on the location and available infrastructure, the use of such facilities cannot be guaranteed. The requirement to store HMEs and chemicals can prompt MA organisations to design temporary storage sites with greater degrees of protection and for longer time frames. The design of a temporary storage site must also prevent any harm to the environment and local population.

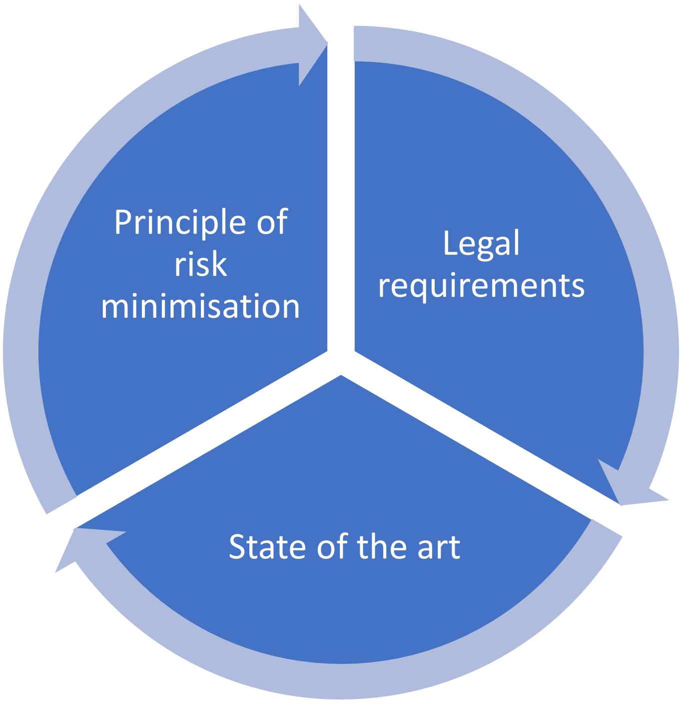

Figure 8. Principles of storing hazardous goods (source: GICHD ©)

Good storage practices for hazardous goods follow the principle of risk minimisation, compliance with legal regulations and the application of state of the art, yet practical, techniques. To ensure this approach is followed / implemented, the development of a comprehensive storage concept in the planning process is advisable.

A comprehensive storage concept should:

- Consider local environmental conditions and adapt storage methods to the hazardous nature of the substances to be stored;
- Identify contradictory measures and procedures early on in the planning process; and
- Comply with legal requirements.

To achieve these goals, the comprehensive storage concept should:

- Include a description of the site conditions;
- Provide details on the type and quantity of HMEs / chemicals to be stored; and
- Outline the constructional, technical and organisational measures to be taken.

NOTE. For appropriate short-term storage (for instance at a search site), analogous protective measures must be taken.

POSSIBLE HAZARDS	IMPACT
fire / explosion	distribution of toxic fumes and vapours, secondary effects of explosions; contamination of soil, surface water and groundwater with firefighting water
flooding	hazard to the environment from contaminated water
leakage or improper disposal	spread of toxic or environmentally hazardous substances

Table 13. Possible impact of improper storage

When hazardous substances need to be stored in containers or in large quantities, the available space in a suitable storage facility often reaches its limit. Hazardous material storage facilities can be used for safe storage. Hazardous material storage facilities offer plenty of space for the safe and versatile storage of water-polluting and flammable substances.

GOOD PRACTICE. Empty chemical packaging can still include hazards. Residual quantities may produce flammable and explosive air-vapour mixtures. Contaminated and uncleaned containers should be treated as full. However, it is advisable to separate them from full packages and mark them as empty.

Organising the storage of chemicals is less of a challenge, as they are commonly stored worldwide for various industrial uses. Commercial providers offer functional and internationally proven solutions to fulfil this task. However, budget constraints and access limitations to operational areas can make it difficult for an MA organisation to resort to support from commercial providers. This may lead to the need to develop ad hoc storage solutions, in order to reduce the risks to as low a level as practically possible. In addition, storage facilities may need to be adapted to specific regional requirements.

NOTE. Standard sea containers (e.g. 40-foot containers) are a good option to generate storage space within a (temporary) storage facility. They offer protection from weather and can be easily air conditioned and ventilated. Containers can be moved and relocated as required. With simple means such as filled sandbags stacked as a wall (traverse), containers can be strengthened to contain the reaction of explosives stored inside or hardened to counter external effects. Alternatively, mechanical handling equipment can be used to create makeshift bunds surrounding a container.

The storage of chemicals without their original packaging, which was designed to mitigate the hazards of storage and transport, will always be challenging. Any non-original packaging that is used must therefore have sufficient mechanical, thermal and chemical resistance to fulfil its task. As a rule, packaging must be approved for transport on public roads. Plastic containers are subject to ageing and thus have a maximum service life; in Europe, this is usually 5 years. Exposure to UV radiation can greatly accelerate ageing.

NOTE. Anyone operating in storage and handling facilities for hazardous substances is responsible for ensuring that measures are taken in accordance with good practice. It is worth noting that some hazards can only occur when chemicals come into contact with other chemicals. To prevent this, necessary attention must be paid to the combined storage of substances at both planning and implementation stages.

10.3.2. CHEMICAL-RELATED STORAGE CONSIDERATIONS

Flammable liquids quickly burn up until they reach explosive decomposition, and accelerate the spread of fire by flowing outwards once a container is breached. Liquids that are less dense than water or immiscible with water, tend to float to the surface of extinguishing water, continuing to burn. Vapours of flammable liquids are generally explosive and can be ignited by sparks or electrostatic discharges. Empty containers that have not been cleaned often contain explosive air-vapour mixtures. Most flammable liquids pose a hazard to soil, subsoil and water.

Solids have a different burning behaviour to liquids. This can range from a glow to a violent burn. The dust of combustible solids can be explosive even if the substance is not dangerous. Solids can smoulder over a long period of time (days to weeks). This can lead to self-heating and a sudden outbreak of fire. Powder must be prevented from trickling onto floors and entering other materials.

Substances liable to spontaneous combustion, including mixtures and solutions (solid or liquid), may ignite very rapidly on contact with air, even in small quantities. Self-heating substances, including mixtures and solutions (solid or liquid), may self-ignite in contact with air when in larger quantities and after a longer period, and without further energy input. Exposing them to high temperatures (sunlight) must be avoided. Furthermore, a rise in temperature due to internal friction during transport and storage must be prevented. Substances liable to spontaneous combustion should be stored separately from other explosives, and oxidising and flammable substances. They should be stored in such a way that they are protected against fire transmission.

Various chemicals react with water to form flammable or explosive gases. Such a reaction generally releases so much heat that the resulting gas ignites itself. These substances should be stored separately from other hazardous substances and preferably not outdoors. Cross-ventilation of the room is advisable. These substances must be stored in tightly closed containers in a dry and cool place. Specific hazards may occur when halogens, acids, water and oxidising agents are stored together.

Oxidising substances, together with combustible substances, form highly flammable or explosive mixtures. These substances are not necessarily classified as hazardous but are sufficient to promote fires in basically flammable substances, such as sugar or wood chips. Special care must be taken with organic peroxides, which combine the properties of oxidising and flammable substances. They generally burn very violently or even explosively. It is advisable to consider storing organic peroxides separately. Oxidising substances should be stored separately from flammable and corrosive substances. Oxidising substances and organic peroxides should not be stored together.

Toxic substances can have a very harmful or even lethal effect on humans, flora and fauna and the environment, even in very small quantities. These chemicals must be stored in such a way that they are inaccessible to unauthorised persons. They must not be stored in the vicinity of human or animal food. When handling toxic substances, the focus must be on self-protection and the protection of others. Employees must be trained regularly in handling, safety and emergency procedures.

Corrosive and caustic substances cause serious damage to health, or even death, when coming into contact with tissue, mucous membranes, eyes or if swallowed. These chemicals can attack and cause metals to decompose. Furthermore, they can form dangerous gases once in contact with the air. Corrosive and caustic substances must be separated from others in combination with which they form dangerous gases, and from substances that promote fire. Containers and collecting trays must be made of medium-resistant material. Acids and alkalis can react with each other, generating a considerable amount of heat and should be stored separately.

Substances that are harmful to health or are irritants can cause damage when ingested or through contact, and / or have environmentally hazardous properties. In the case of liquid substances, leakage into soil, surface water and groundwater must be prevented. In the case of solid substances, rainwater or firefighting water can lead to their infiltration into the surrounding environment. Solids can also be dispersed by wind. During storage, it must be ensured that no substances that are harmful to health or which are irritants can enter the soil, subsoil, surface water or groundwater through their release.

10.3.3. CONSTRUCTIONAL, TECHNICAL AND ORGANISATIONAL MEASURES

Organisational measures have proven to be an effective and inexpensive tool to increase safety and prevent accidents in all kinds of storage.

Organisational measures ensure:

- The permanent surveillance and documentation of the stored HMEs and chemicals;
- That the storage infrastructure and system are fit for the task;
- The prevention of handling errors;
- The application of good working practices;
- The protection of stored goods from environmental influences or external events;
- That the prerequisites are set for an accident investigation; and
- Security against theft.

Risk assessments of the properties of temporarily stored HMEs and chemicals establish the preconditions for safe and well-organised storage. Questions that should be asked during such assessments include:

- What hazards do the stored goods present, because of their chemical and physical properties?
  - Explosion and fire behaviour;
  - Reactivity;
  - Chemical and physical stability;
  - Emission of fumes and vapours;
  - Decomposition effects on containers, packaging, etc; and
  - Toxic threat to humans and the environment.
- What issues need to be considered in the surroundings of the temporary storage site?
  - Safety distances;
  - Neighbouring infrastructure;
  - Floor drains;
  - Access by unauthorised personnel; and
  - Natural hazards.

GOOD PRACTICE. Floor drains in the vicinity must be closed or secured in such a way that neither hazardous substances nor extinguishing water can flow away unchecked.

- Which counter measures can decrease the hazards and increase storage safety? Measures include:
  - Assessable documentation of the stored chemicals;
  - Regulated access;
  - Danger-specific training plan for staff;
  - Incident reaction plan, including fire protection plan and equipment;
  - Phlegmatisation of HMEs and chemicals (e.g. storing phosphorus in water);
  - Separation of goods by their hazardous material classification;
  - Separation of primary and secondary explosives;
  - Separation of flammable substances, propellants and pyrotechnics;
  - Organisation of the spatial separation of stockpiles;
  - Separation of chemicals that must not be stored together, as contact may lead to intense reactions;
  - Determination of the maximum safe quantity of explosives per storage location;
  - Structural protection measures;
  - Creation of fire compartments;
  - Limitation of stored amounts per fire compartment;
  - Provision of appropriate PPE;
  - Provision of threat-adapted first aid materials such as eye showers; and
  - Provision of oil binders, chemical binders and shovels.
- Are there external threats to a storage facility including man-made and natural threats (such as flooding)?
- Which external sources of danger or facilities worthy of protection are in the vicinity?

Hazards to the surrounding area do not only include fragmentation resulting from a detonation. The effects of fragmentation can be minimised by the limitation of amounts of chemicals per stockpile, and structural protection measures. Threats to the surrounding area also include the toxic and caustic properties of chemicals. Fumes and vapours can be a threat to health. Preventing leakage of chemicals into the water supply is as important as fire protection. Depending on the amount and type of a substance, contamination of the environment can negatively affect lives for months or years to come.

GOOD PRACTICE. Building materials should not contribute to the amount of fragmentation in the event of an explosion or fire hazard.

Risk assessment will provide courses of action on how to conduct safe and organised storage, although it should be kept in mind that proper storage will usually be a challenge during MA operations. Storage of hazardous goods will require great improvisational talent, planning skills and good adaptability on behalf of the organisation, especially if a state's support is limited. In post-conflict scenarios, meeting industrial standards for the storage of hazardous substances can be hard to achieve but should be considered as the goal, regardless.

Industrial guidelines[64] propose seven main steps to assessing a planned storage facility:

- Step 1 – stock list.
  A comprehensive stock list should be created. Which substances and chemicals are expected to be stored? It will always be challenging to foresee all types of HME and chemicals.
- Step 2 – classification and hazardous properties.
  Classification and hazardous properties of the stored HMEs and chemicals are added to the list. This includes the Globally Harmonized System of Classification and Labelling of Chemicals (GHS), classes of water hazards, flashpoint,[65] health, environmental and explosion hazards. Depending on the substances, further relevant items may be added.
- Step 3 – maximum storage quantities.
  The expected maximum quantities of substances and products to be stored are added to the list, which must respect applicable legal limits. Due to the nature of the list, many of the items and entries can be based on assumptions.
- Step 4 – determination of the corresponding storage class.
  Determine the corresponding storage classes:[66]
    - Explosive substances;
    - Infectious substances;
    - Radioactive substances;
    - Liquefied and pressurised gases;
    - Oxidising substances / organic peroxides;
    - Spontaneously combustible substances;
    - Gases flammable with water;
    - Flammable solids;
    - Toxic substances;
    - Corrosive and caustic substances;
    - Other liquids;
    - Other solids with hazard labels; and
    - Other solids without hazard labels.

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[64] Hans-Peter Beutler et al., *Lagerung gefährlicher Stoffe, Leitfaden für die Praxis* (*Storage of Hazardous Substances – Practical Guide*) (Frauenfeld: Environmental Departments of the cantons of Nordschweiz, Thurgau and Zürich, as well as GVZ Gebäudeversicherung Kanton Zürich, 3rd Revised Edition, 2018).

[65] If an ambient temperature exceeds the flashpoint of a substance, its flammable vapours form an explosive atmosphere together with the ambient air.

[66] In each storage class, substances with hazard characteristics that are of the same type are grouped together and consequently also require the same safety measures. Some storage classes (e.g infectious substances) are listed for the sake of completeness only, as they are not relevant to HMEs or their precursors.

- Step 5 – allocation.
  Available storage quantities are assigned to the corresponding storage classes.
- Step 6 – requirements for storage rooms / facilities.
  Requirements for storage rooms / facilities such as fire compartments, ventilation, leakage containment, extinguishing agents, explosion protection and so on, are determined.
- Step 7 – implementation.
  Implementation of the results of the planning of the storage facility. The relevance of the planning to the current situation is to be checked periodically.

NOTE. A proper assessment of the storage facility will help to define equipment and procedures necessary to counter an emergency such as fire or contamination.

It is appropriate to define specific storage areas within the available space. Doing this can minimise:

- The necessity for and amount of constructive protection measures;
- Efforts needed for fire protection measures;
- The required amount of collecting trays; and
- The required amount of chemical binders.

HINT. A collection tray must be chemically resistant and have the usable volume of at least the largest package stored.

An underrated but effective tool is bookkeeping of stored substances, their amount, location, as well as having a visual overview of possible paths and cross sections of the infrastructure used. This information must be easily accessible for staff and external support, in case of an emergency.

GOOD PRACTICE. Appropriate and well-organised documentation supports the prevention of incidents and can help minimise their impact. It provides information on the type of chemical, associated hazard(s) and location in the storage site. Documentation should include rules establishing when firefighting should be stopped, in case of fire, due to the increased risk of explosion and when evacuation should be carried out. In addition, proper bookkeeping prevents stored chemicals from being forgotten and the potential increased risk of explosion or fire due to ageing.

It is good practice to mark the individual stockpiles (e.g. containers) according to the hazards they contain, for instance explosive, corrosive material, biohazard, etc. Printouts or downloads of the safety data sheet or hazardous material information should be added to the documentation as well.

NOTE. If an organisation has its own storage facilities for the energetic substances required for its operations, it is advised to store HMEs and explosive precursor chemicals separate from these stockpiles.

Temporary storage of HMEs and chemicals should be split with regard to explosive and other hazards. Within enclosed storage spaces, there should be an option to ventilate areas before entering. In enclosed spaces, proactive measures (prevention of dust dispersion, for instance) to counter the threat of dust explosions are also required.

WARNING. It is not appropriate to store HMEs and hazardous chemicals together with flammable materials such as wood, cardboard boxes, paper or plastics.

10.3.4. SPATIAL SEPARATION

Depending on the available space, funding, support and the type of HMEs and chemicals, a combination of different storage solutions may be implemented at a temporary storage site. All solutions are aimed at protection from fire and explosion, as well as minimising the effects of an incident both in the temporary storage site and to the surrounding area.

Spatial separation increases the safety of a temporary storage site. Some separation and protection measures target very specific threats defined by the storage classes. The figure below demonstrates the concept of ad hoc storage, separate storage and selective storage.

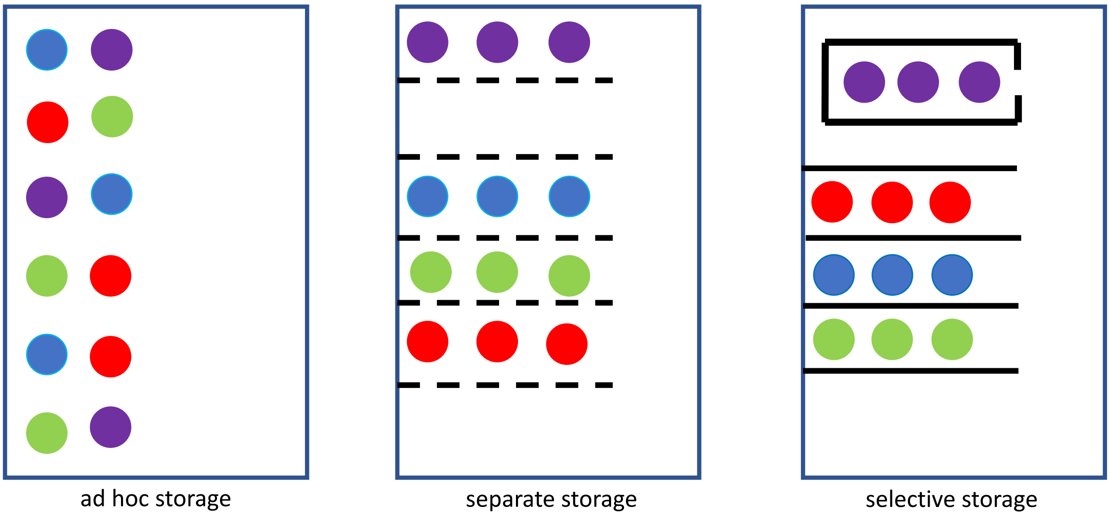

Figure 9. Storage options (source: GICHD ©)

AD HOC STORAGE

HMEs and chemicals can be temporarily stored as they are delivered. This is better applied to chemicals that do not pose specific threats or which have no limitations based on their storage class. This is a very cost-effective approach.

SEPARATE STORAGE

HMEs and chemicals having storage limitations because of their chemical and physical properties should be stored separately. Those having similar characteristics and responses can be stored in the same fire compartment. For each compartment, protective conditions must be implemented, for example minimum distances, separate collecting trays and maximum storage quantities. An increase of space between individual stockpiles improves storage safety, prevents the progress of fire and minimises the chances of a sympathetic detonation (unintended, accidental initiation of an explosive by a nearby detonation, sometimes referred to as flashover) from one stockpile to another. A proven rule for the storage of explosives has always been that increased distance improves safety.

⚠ **GOOD PRACTICE: Fire protection measures are more effective if substances are stored separately according to their firefighting requirements and storage class. One example is to separate out chemicals which must not be extinguished with water and make the appropriate firefighting equipment available at that location.**

SELECTIVE STORAGE

Selective storage divides HMEs and chemicals strictly according to their properties, compatibility and predicted hazard. Specific construction techniques are used to mitigate the effects of an explosion, as are separate fire compartments. If available space becomes compromised and no additional storage is available, separate storage can be implemented in some bays but only with items deemed to pose the lowest risk.

NOTE. If disposal is not possible, it is better to store safely, using all available storage techniques, as opposed to leaving HMEs and explosive precursor chemicals open to the elements or at risk of further illicit diversion.

10.4. FIREFIGHTING

Firefighting involving HMEs or chemical precursors should always be carried out by personnel trained and equipped for the task. The following basic considerations may be of use if an incipient fire is encountered or for the preparation of temporary storage.

10.4.1. SAFETY CONSIDERATIONS

Some chemicals do not burn but have an oxidising effect. This property increases the fire hazard when in contact with flammable substances and can significantly promote an existing fire. In case of the involvement of such chemicals in a surrounding fire it is appropriate (if safe) to:

- Cool surrounding containers and vessels with water spray;
- Move containers out of the danger zone if possible; and
- Eliminate sources of ignition.

NOTE. Specific information on the behaviour of a substance when exposed to heat or fire is provided by safety data sheets, including general firefighting methods.

HINT. Vapours arising from a fire can be suppressed with a water spray.

WARNING. Increased pressure caused by fire within containers may cause them to burst open or their contents to deflagrate or detonate.

Some HMEs, such as ammonium nitrate, can release hazardous gases such as nitrogen oxide and carbon monoxide when exposed to heat. Under such circumstances it may be necessary to wear a self-contained breathing apparatus and chemical protective suits when conducting firefighting.

The effect of a fire on HMEs or precursor chemicals with explosive properties is hard to assess or predict given the many variables, such as melting point, impurities, ignition temperature, particle size, density and confinement. Necessary measures (or safety measures) include taking cover immediately, clearing and cordoning off as large an area as necessary and evacuating as appropriate. The fire should be tackled, if possible, from a safe position.

WARNING. In the event of a sudden release and swirling up of large quantities of dust, there is the risk of a dust explosion. Taking cover immediately is the appropriate response.

WARNING. Some chemicals decompose violently when coming into contact with water.

10.4.2. PORTABLE FIRE EXTINGUISHERS

Portable fire extinguishers are an appropriate means of countering emerging fires. It is important that a fire extinguisher contains the appropriate extinguishing agent to fulfil this task and must be selected based on the expected fire load and fire class.

FIRE LOAD	Solid substances (Europe: fire class A)
	Liquid substances (Europe: fire class B)
	Gaseous substances (Europe: fire class C)
	Metal fires (Europe: fire class D)
	Grease fires (Europe: fire class F)

Table 14. Classification of fire loads

Fire extinguishers are divided into rechargeable and continuous pressure fire extinguishers. Compared to continuous pressure, rechargeable extinguishers are much more complex in terms of construction and technical specifications. The advantages of rechargeable fire extinguishers compared to continuous pressure fire extinguishers include:

- Easy and ample dosing of the extinguishing agent, even for inexperienced users;
- Ease of maintenance;
- Reliable handling; and
- A longer legal operating time (typically 25 years, with continuous pressure fire extinguishers lasting only 20 years).

Fire extinguishers are available with regular extinguishing agents like powder, foam, water and carbon dioxide (CO_2). The fire class determines the choice of the appropriate extinguishing agent.

POWDER

ABC extinguishing powder is the most widely used extinguishing agent. It consists mainly of phosphate and ammonium sulphate (approx. 90% in total).

The advantage of ABC extinguishing powder is that it can be used universally for fire classes A, B and C. In principle, extinguishing powder has a high extinguishing capacity. This can vary considerably depending on the type of fire.

The disadvantage of this type of extinguishing agent is the extremely heavy dust formation and its associated contamination. Electrical devices react sensitively to the fine dust produced by ABC extinguishing powder.

Using powder fire extinguishers to address small incipient fires can quickly lead to significant damage in certain contexts because of the contamination with the ABC powder itself.

Special extinguishing powders are also used to extinguish metal fires (fire class D).

FOAM

Foam fire extinguishers are cleaner than powder fire extinguishers, but their performance is comparatively low. At the same time, very good extinguishing results can be achieved depending on the kind of material that is burning.

Foam fire extinguishers are not powerful enough to extinguish fire classes A and B. They therefore have a more limited use, compared to that of powder fire extinguishers. For most commercial, public and private applications, however, a foam extinguisher is an appropriate alternative to a powder fire extinguisher. In outdoor areas, care should be taken that a frost-proof version (via inclusion of additives) is chosen.

WATER

Water fire extinguishers are intended exclusively for extinguishing class A fires. Additives are included that increase the extinguishing performance compared to that of regular water. Extinguishing fire with water is cleaner than with powder but less effective than with foam.

Grease fires (fire class F) are extinguished with specially manufactured water and / or foam fire extinguishers.

CARBON DIOXIDE CO_2

Carbon dioxide fire extinguishers extinguish with non-flammable gas. In the process, the gas displaces the oxygen, thus smothering the fire. This enables the cleanest way of extinguishing, and is completely residue free. Due to its physical properties, this extinguishing agent is only suitable for class B fires. However, carbon dioxide fire extinguishers are also used to protect electrical systems, for example in server rooms and in the computer sector.

11. CONCLUSION

Image 204. Containers with HMEs prior to their disposal (source: CAR ©)

The continued deployment of IEDs around the globe has focused attention on the issue of HMEs. Sadly, the trend of IED use is not abating, instead their on-going presence continues to cause innocent victims in large numbers.[67] As highlighted by the Landmine Monitor 2021, "The majority of casualties in 2020 were reported in countries experiencing armed conflict and which suffered contamination with mines of an improvised nature.[68] Notably, many of the devices defined as "improvised mines" make use of HMEs in their construction, and the risks to personnel operating in these environments and their populations from HMEs, must therefore be addressed.

This chapter has been produced to address the immediate need for basic information related to the proliferation of HMEs in environments affected by IEDs. It aims to support the effort to keep MA practitioners (as well as other humanitarian workers and first responders) safe by allowing them to better plan for and manage the risks associated with HMEs – both explosive and non-explosive. Knowledge of the physical and chemical properties of HMEs and their chemical precursors plays an important role in strengthening safety measures and this information therefore forms the basis of this chapter.

Unfortunately, encountering HMEs, HME-contaminated storage sites, or HME manufacturing sites, will always entail a degree of risk and will require that decisions are made on a case-by-case basis by field personnel. The very nature of "improvised" devices is that they are ever-changing and continuously evolve in terms of their structure. As a result, the knowledge presented in this chapter, targeted to the needs of humanitarian personnel, supports evidence-based decisions to identify and counter those hazards.

Through the review of various safety aspects that are relevant to dealing with HMEs, it is hoped that national programmes and MA operators will also be supported in the development of national standards and standard operating procedures (SOPs) in environments affected by IEDs. For example, suggestions

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[67] In 2020, at least 7,073 casualties of mines/ERW were recorded, which represents an increase over the 5,853 casualties recorded in 2019, according the Landmine Monitor 2021. The majority of these casualties were as a result of improvised mines. http://www.the-monitor.org/en-gb/reports/2021/landmine-monitor-2021/the-impact.aspx

[68] Ibid.

in terms of equipment – in particular PPE – that can shield personnel from the effects of HMEs and allow them to interact more safely with these substances, have been provided. Appropriate PPE will most certainly improve the likelihood that HMEs can be removed and/or destroyed in as safe a manner as possible by appropriately-trained personnel. Ensuring that MA and other humanitarian personnel understand what they should avoid when encountering HMEs, as well as the steps they should take when HMEs are found, is another important objective of this chapter that can inform standards and procedures.

The content on HMEs has been produced with the support and participation of a number of organisations. In particular, the GICHD would like to thank Bundeswehr CBRN Defence Command, Brimstone Consultancy Limited, Conflict Armament Research and the Fondation Suisse de Déminage, for their valuable support in preparing this chapter.

Finally, due to the changing nature of IEDs, this document must continue to evolve and incorporate new information from the field. The GICHD therefore counts on the input of MA stakeholders engaged in IED-affected environments to provide feedback on the content, including where gaps may occur with regards to information provided on HMEs encountered in the field. It is essential that information is shared and that MA personnel are equipped with the most recent and complete information possible to ensure the safety and effectiveness of humanitarian work where IEDs are found. In order to reach this goal, we count on your continued support.

12. LEXICON OF ABBREVIATIONS

ANAL	ammonium nitrate–aluminium
ANFO	ammonium nitrate–fuel oil or ANC
ANIS	ammonium nitrate–icing sugar
ANMAL	ammonium nitrate–nitromethane–aluminium
ANNIE	ammonium nitrate–nitrobenzene
ANNM	ammonium nitrate–nitromethane
ANS	ammonium nitrate–sugar
CHP	concentrated hydrogen peroxide
DDNP	dinitrobenzenediazoxide or diazodinitrophenol, DINOL®
EGDN	ethylene glycol dinitrate or nitroglycol
ETN	erythritol tetranitrate
FOI	figure of insensitivity
GHS	Globally Harmonized System of Classification and Labelling of Chemicals
HME(s)	home-made explosive(s)
HMTD	hexamethylene triperoxide diamine
IATG	International Ammunition Technical Guidelines
IED	improvised explosive device
IMAS	International Mine Action Standard
LEL	lower explosive limit
MA	mine action
MEKP	methyl ethyl ketone peroxide or butanone peroxide
NG	nitroglycerine or glyceryl trinitrate
PE	polyethylene
PETN	pentaerythritol tetranitrate or nitropenta
PLX	Picatinny Liquid Explosive or myrol
PP	polypropylene
PPE	personal protective equipment
PTFE	polytetrafluoroethylene or Teflon™
PVC	polyvinylchloride

RDX	trimethylentrinitramin; or Hexogen
SDS	safety data sheet
SOPs	standing operating procedures
TATP	acetone peroxide or triacetone triperoxide
TEA	triethylaluminium
TNT	trinitrotoluene
TPA	thickened pyrophoric agent
UEL	upper explosive limit

13. GLOSSARY OF TERMS

alkali metals[69]**.** lithium, sodium, potassium, rubidium, caesium and francium.

black powder. intimate mixture of sodium nitrate or potassium nitrate with charcoal or other carbon, with or without sulphur. (IATG 01.40 Glossary of terms, definitions and abbreviations, 3rd edition, March 2021)

blast. a destructive wave of gases or air produced in the surrounding atmosphere by an explosion. The blast includes a shock front, high pressure behind the shock front and a rarefaction following the high pressure. (IATG 01.40, 3rd edition, March 2021)

booster. explosive device used as a donor charge to amplify the energy to the acceptor charge. (IATG 01.40, 3rd edition, March 2021)

brisance. the shattering effect of an explosive or explosion. (IATG 01.40, 3rd edition, March 2021)

catalyst. in chemistry, any substance that increases the rate of a reaction without itself being consumed. (©2021 Encyclopædia Britannica, Inc.)

charge. a bagged, wrapped or cased quantity of explosives without its own integral means of ignition. Secondary means of ignition may or may not be incorporated. (IATG 01.40, 3rd edition, March 2021)

combustion. rapid chemical combination of a substance with oxygen, involving the production of heat and light. (Oxford English Dictionary, ©2021 Oxford University Press)

confinement. the characteristics of the casing of a charge, which restrict the expansion of the decomposition products when the explosive substance reacts. (IATG 01.40, 3rd edition, March 2021)

contamination. impurity of an HME with a substance(s) other than that intended to be part of the improvised explosive.

critical diameter. the minimum diameter of an explosive charge at which detonation can still take place. (Rudolf Meyer, Josef Köhler and Axel Homburg, Explosives. Sixth Edition. Wiley-VCH Verlag GmbH & Co. KGaA, 2007)

dangerous goods. items classified under the United Nations (UN) system within Classes 1 to 9 in accordance with the UN Transport of Dangerous Goods Regulations (Orange Book). (IATG 01.40, 3rd edition, March 2021)

decomposition. chemical reaction of a substance which is not a detonation or deflagration, resulting in significant change in properties. (IATG 01.40, 3rd edition, March 2021)

deflagration. a reaction of combustion through a substance at sub-sonic velocity in the reacting substance. (IATG 01.40, 3rd edition, March 2021)

deflagration to detonation transition. the transition to detonation from an initial burning reaction. (IATG 01.40, 3rd edition, March 2021)

density. mass of a unit volume of a material substance. (©2021 Encyclopædia Britannica, Inc.)

detonation. reaction which moves through an explosive material at supersonic velocity in the reacting material. (IATG 01.40, 3rd edition, March 2021)

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[69] If no source is added, the definition is taken from this publication.

detonation velocity. velocity at which the detonation travels through the explosive charge or column in m/s. (IATG 01.40, 3rd edition, March 2021)

detonator. a device containing a sensitive (primary) explosive intended to produce a detonation wave. (IATG 01.40, 3rd edition, March 2021)

diurnal cycling. the exposure of ammunition and explosives to the temperature changes induced by day, night and change of season. (IATG 01.40, 3rd edition, March 2021)

dust explosion. the result of the rapid combustion of fine solid particles, such as organic dusts (sugar or wood), metal dusts (aluminium and magnesium); polymer-based dusts and carbonaceous dusts. (E. Salzano, in Reference Module in Chemistry, Molecular Sciences and Chemical Engineering, 2014)

equivalence (TNT). when explosives having a significantly more or less powerful effect than TNT are being considered, a TNT equivalent may be used to determine the appropriate quantity distance(s). (IATG 01.40, 3rd edition, March 2021)

explosion. sudden release of energy producing a blast effect with the possible projection of fragments. (IATG 01.40, 3rd edition, March 2021)

explosive. a substance or mixture of substances, which, under external influences, is capable of rapidly releasing energy in the form of gases and heat. (IATG 01.40, 3rd edition, March 2021)

flash composition. a pyrotechnic composition (mixture of oxidiser and (metallic) fuel) which burns bright and quickly and, if confined, produces a loud noise.

flashpoint. the lowest temperature at which a volatile substance evaporates to form an ignitable mixture with air in the presence of an igneous source and continues burning after the trigger source is removed. (Joaquín Isac-García et al., Experimental Organic Chemistry, 2015)

fuel. a substance or compound that is electron rich and acts within an explosive as a chemical reducing agent.

fuel-air explosion. occurs when fuel vapour mixes with ambient atmospheric air and when mixing is complete, is initiated by an ignition source.

fuse. a device for protecting an electrical circuit against damage from an excess current by the melting of a fuse element to break the circuit. Also used for burning fuses, i.e. those fuses which do not use detonation to ignite the explosive train. (IATG 01.40, 3rd edition, March 2021)

fuze. a device that initiates an explosive train. (IATG 01.40, 3rd edition, March 2021)

harm. physical injury or damage to the health of people or damage to property or the environment. (IATG 01.40, 3rd edition, March 2021)

hazard. potential source of harm. (IATG 01.40, 3rd edition, March 2021)

hazard class. the UN recommended system of nine classes for identifying dangerous goods. Class 1 identifies explosives. (IATG 01.40, 3rd edition, March 2021)

high explosive (HE). substance or mixture of substances that can undergo a fast internal decomposition reaction leading to a detonation in its normal use. (IATG 01.40, 3rd edition, March 2021).

A substance or mixture of substances which, in their application as primary, booster or main charge in ammunition is required to detonate. (IATG 01.40, 3rd edition, March 2021)

Home made explosive. a combination of commercially available ingredients combined to create an explosive substance (2014). (IMAS 04.10 Glossary of mine action terms, definitions and abbreviations, Second Edition (Amendment 10, February 2019)

homogeneous mixtures. a mixture having the same composition and the same physical and chemical properties in all parts. Heterogeneous mixtures consist of at least two immiscible phases. Their individual components may be present in different aggregate states and / or consist of different substances.

hotspot. spot in an explosive where adiabatic compression of small, occluded gas bubbles generates up to 400°C-500°C heat.

hygroscopic. readily water-attracting.

hypergolic reaction. the self-igniting effect between mixed liquids.

ignition. the initial heating of a deflagrating explosive or pyrotechnic composition, by flame or other source of heat, up to its point of inflammation. (IATG 01.40, 3rd edition, March 2021)

improvised explosive device (IED). a device placed or fabricated in an improvised manner incorporating explosive material, destructive, lethal, noxious, incendiary, pyrotechnic materials or chemicals designed to destroy, disfigure, distract or harass. They may incorporate military stores but are normally devised from non-military components. (IATG 01.40, 3rd edition, March 2021)

incendiary munition. ammunition, containing an incendiary substance and designed to give a primary incendiary effect which may be a solid, liquid or gel including white phosphorus. (IATG 01.40, 3rd edition, March 2021)

initiation. refers to the commencement of a deflagration or detonation reaction.

loading density. ratio between explosive weight and the amount of space in which an explosive is detonated (compactness).

low explosive. deflagrating explosive used for propulsion. *See* propellant (IATG 01.40, 3rd edition, March 2021)

low order detonation. an incomplete and relatively slow detonation, being more nearly a combustion than an explosion. (IATG 01.40, 3rd edition, March 2021)

oxidiser. a substance that is combined with a fuel to produce an energetic material. (IATG 01.40, 3rd edition, March 2021)

phlegmatiser. a substance added to an explosive to enhance its safety in handling and carriage.

porosity. the ratio of void volume to total volume of a substance or mixture of substances.

prill. a pellet or solid globule of a substance formed by the congealing of a liquid during an industrial process.

primary explosive. an explosive substance which is sensitive to spark, friction, impact or flame and is capable of promoting initiation in an unconfined state. (IATG 01.40, 3rd edition, March 2021)

An explosive that is extremely sensitive to stimuli such as heat, friction and/or shock and requires special care in handling. Generally, primary explosives are synonymous with initiating explosives. (IATG 01.40, 3rd edition, March 2021)

propellant. deflagrating explosive used for propulsion. (IATG 01.40, 3rd edition, March 2021)

pyrophoric. a substance capable of spontaneous ignition when exposed to air, such as white phosphorous. (IATG 01.40, 3rd edition, March 2021)

pyrotechnic. a device or material that can be ignited to produce light, smoke or noise. (IATG 01.40, 3rd edition, March 2021)

reactant. substance participating in the chemical reaction.

risk management. the complete risk-based decision-making process. (IATG 01.40, 3rd edition, March 2021)

safe. the absence of risk. Normally the term tolerable risk is more appropriate and accurate. (IATG 01.40, 3rd edition, March 2021)

'safe to move'. a technical assessment, by an appropriately qualified technician or technical officer, of the physical condition and stability of ammunition and explosives prior to any proposed move. (IATG 01.40, 3rd edition, March 2021)

secondary explosive. an explosive substance which requires a large stimulus to detonate.

sensitiser. substance used to increase susceptibility to ignition (initiation). (IATG 01.40, 3rd edition, March 2021)

sensitiveness. a measure of the relative probability of an explosive being ignited or initiated by a prescribed stimulus. It is used in the context of accidental ignition or initiation. (IATG 01.40, 3rd edition, March 2021)

sensitivity. a measure of the stimulus required to cause reliable design mode function of an explosive. (IATG 01.40, 3rd edition, March 2021)

solution. in chemistry, is a homogenous mixture of two or more substances in relative amounts that can be varied continuously up to what is called the limit of solubility. (©2021 Encyclopædia Britannica, Inc.)

stabiliser. a substance which stops or reduces auto-catalytic decomposition of explosives. (IATG 01.40, 3rd edition, March 2021)

stability. the physical and chemical characteristics of ammunition and explosives that impact on their safety in storage, transport and use. (IATG 01.40, 3rd edition, March 2021)

standing operating procedures (SOPs). instructions that define the preferred or currently established method of conducting an operational task or activity. (IATG 01.40, 3rd edition, March 2021)

strength. determined by the gas volume produced and the energy (heat) created by the explosion as well as the detonation velocity.

sympathetic detonation. unintended, accidental initiation of an explosive by a nearby detonation, sometimes referred to as flashover.

tinder. substances that lower the ignition temperature of a low explosive.

14. LIST OF HMEs AND CHEMICALS

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