CHAPTER 1
INTRODUCTION TO THE TEXTBOOK

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1 INTRODUCTION TO THE TEXTBOOK

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1.1 PURPOSE OF THE TEXTBOOK

1.1.1 Background

The last edition of the Services Textbook of Explosives was written in 1988 and produced as Joint Services Publication (JSP) 333. While most of the science and technology in that edition remains current there has been significant changes to legislation with the introduction of MSER (2005) [(1)] now superseded by Explosives Regulations 2014[(2)] and in Explosives Safety Management within the MOD, with new Regulations including JSP 520 *Safety and Environmental Management of Ordnance, Munitions and Explosives over the Equipment Acquisition Cycle*.

Further changes have been the development and introduction of MOD Insensitive Munitions (IM) policy and its effect on munition design and choice of explosive formulations. Many of the explosive materials cited in the 1988 edition are now obsolete and can be found in the History of Explosives chapter. Those explosives currently in service are in the chapters that relate to explosive materials.

To produce this textbook, subject matter experts from academia, industry and the MOD were chosen as chapter authors. An Editorial Board with representatives from Service users and academia provided oversight for suitability of purpose.

1.1.2 Target Audience

This textbook is intended to assist all of those in the MOD that acquire, use or manage Ordnance, Munitions and Explosives (OME), including the Royal Navy, Army, Royal Air Force and MOD Civilians. A significant effort has been made to engage with all potential users of this textbook. It has been recognised that different technical levels will be relevant across a wide range of potential users. To reach the widest audience, each chapter, where appropriate, is structured to have a basic introduction at Awareness level, then with greater detail for Practitioners and finally information relevant to Experts in that subject.

1.1.3 Purpose

The textbook is to provide an electronic edition that brings up to date the 1988 edition with content that is accurate and comprehensive.

1.2 STRUCTURE OF THE TEXTBOOK

The textbook is designed to provide information on how explosives work, how they are applied in weapon systems and how their safety may be ensured through testing and regulation. Other sources of information that provide further detail or more in-depth analysis are referenced and summarised where appropriate. For example, Joint Services Publications such as JSP 520 cited above and MOD explosives regulations (JSP 482) are relevant to explosives in the defence environment. It is not the purpose of this textbook to repeat their contents; instead this document details the fundamental principles that underpin explosives in defence.

The textbook is structured around 5 themes:

1. An introduction to the defence requirements for explosives and a history of explosives that have found service use.
2. The relevant legal and regulatory frameworks, policies and standards relevant to services use of explosives and safety management.
3. The science behind how explosives work their chemistry, toxicity, detection and effects.
4. Explosives currently employed in weapon systems and explosives of interest in defence such as improvised and commercial explosives.
5. The processes applied to ensure they are safe and suitable for service use including qualification, life assessment, vulnerability assessment and electrical safety.

The textbook is designed and constructed to be read electronically and has been mapped to provide, within the text, hyperlinks between a subject and supporting material to avoid the need for repetition. Chapters will contain references together with a bibliography of additional source material.

1.3 DEFENCE REQUIREMENTS FOR EXPLOSIVES

1.3.1 Defining Explosive

There are several ways that an explosive can be defined. In simple terms an explosive is the energetic component or filling within a munition. For a more detailed definition often the reference document is Recommendations on the TRANSPORT OF DANGEROUS GOODS[3] which includes the definition:

"Explosive substance is a solid or liquid substance (or a mixture of substances) which is in itself capable by chemical reaction of producing gas at such temperature and pressure and at such a speed as to cause damage to the surroundings. Pyrotechnic substances are included even when they do not evolve gases."

Further definitions include:

"Pyrotechnic substance is a substance or a mixture of substances designed to produce an effect by heat, light, sound, gas or smoke or a combination of these as the result of non-detonative self-sustaining exothermic chemical reactions."

"Explosive article is an article containing one or more explosive substances."

For the purpose of transport, all of these are classed as Dangerous Goods Class 1 – Explosive. It also should be noted that the publication states that "Transport of explosive substances which are unduly sensitive or so reactive as to be subject to spontaneous reaction is prohibited." The definition of explosives for the purpose of safe, practical use within the MOD excludes substances that can produce an explosive or pyrotechnic effect but would be considered unsafe to use. These are not excluded from explosives that are improvised and employed in criminal acts including terrorism and these are included in the textbook in Chapter 16 (link to 16).

One further type of explosive is the mixture of a flammable gas, vapour or finely powdered solid with a gaseous source of oxygen, usually air. These may be produced by accident or intentionally as a weapon type and are known as fuel-air explosives as described in Chapter 9 (link to 9.4).

Many dictionary definitions of the term 'explosive' assume that an explosive is a substance that will produce an explosion. However, as noted above, pyrotechnics are classed as explosives, most of which do not display that property. Taking this argument further rocket propellant can be a substance that by chemical reaction produces gas at high temperature but again does not produce an explosion but instead produces thrust.

The one common characteristic that covers all substances that may be encompassed in the definition of 'explosive' is that they are chemicals or mixtures of chemicals that all produce heat by self-sustained chemical reaction. Many also produce gas as a product of this reaction but the speed of reaction may vary considerably. Fast reactions, where the explosive charge is all consumed in thousandths or millionths of a second, lead to explosion whereas slow reactions lead to sustained burning for timescales generally measured in seconds.

1.3.1.1 Defining explosion

An explosion is often defined as a rapid expansion of gas capable of causing damage. An explosion can be created by more than just an explosive and can be caused by three means; physical, chemical and nuclear. It is considered that the largest explosion ever witnessed on earth was a physical explosion. The eruption of the volcano known as Krakatoa in August 1883 allowed sea water to pour in to the collapsing caldera where it immediately was converted to its gaseous state. The expansion created a blast, which has been estimated as having the equivalence of 200 million tonnes of TNT. Here a change of state from liquid to gas created the gaseous expansion in a timeframe necessary to

form a blast wave. A more common physical explosion is simply the bursting of a pressure vessel where high pressure gas can expand rapidly on release.

Nuclear explosions also create rapid gas expansion but in this case it is created by the immense heat released in the nuclear fission or fusion process that simply expands anything in contact with that source of heat. For an above-ground nuclear explosion this would be the surrounding air. Chemical explosives also release heat on explosion but this is insufficient on its own to heat the surroundings to cause rapid gas expansion. To create an effective chemical explosion both heat and gas must be released together thus producing the necessary conditions.

A more correct description of an explosion would be a rapid expansion of gas capable of performing work. For example when a gun is fired there is a controlled explosion inside the breech and barrel of the gun when a rapid expansion of gas certainly occurs in thousandths of a second. The sound of gunfire is then an audible explosion coming from the rapidly expanding hot gas as it exits the muzzle at very high pressure.

1.3.2 Explosives for Application in Defence

1.3.2.1 The Role of explosives in defence

Ever since the discovery of Black Powder, or Gunpowder, explosives have provided advantage on the battlefield over weapons operated by human effort. Until the recent development of Directed Energy Weapons such as lasers all weapon systems relied on explosives for their effect, whether this was a gun propellant for pistols and rifles, rocket propellant for missiles or warhead explosives for artillery shells. Even nuclear weapons rely on conventional explosives to trigger the nuclear explosion.

Explosives provide the energy for delivery systems to gain access to remote targets and then often the destructive effect to neutralise or destroy them. As pyrotechnics they provide support to operations through the provision of signalling with coloured light and smoke, illumination, screening and distraction. Complex munitions themselves will often rely on pyromechanisms as part of their operating systems as do military aircraft. Safe, reliable and effective explosives are critical to the operations of all Armed Forces.

1.3.2.2 Categorisation of explosive types

Explosives for defence use are normally categorised as:

- High Explosives (for warheads, shells, grenades, demolition charges, mines, etc.)
- Propellants
    - Gun propellants
    - Rocket propellants
- Pyrotechnics

Another way of categorising explosives is by the process through which they release their energy:

- High Explosives
- Low Explosives

High Explosives detonate (link to 7.1.2) creating a shockwave within the explosive that has the ability to shatter anything in contact with that explosive but also due to the speed of explosion the ability to produce the damaging effect through rapid gas expansion known as blast (link to 9.1.1). Low Explosives undergo a burning reaction (link to 7.1.1) where heat transfer not shock causes the explosion process to occur. Propellants and pyrotechnics are Low Explosives. It is not uncommon for explosives to be grouped as High Explosives, Propellants and Pyrotechnics although there is a fourth group, Pyromechanisms (link to 15.1.1), which are explosive articles that have links to Propellants and Pyrotechnics and are designed to use explosive energy to provide motive force.

A third way that explosives are categorised is in regard to the ease by which they can be initiated. The terms used are Primary and Secondary Explosives where Primary Explosives are easily initiated and are used as the way an explosive event is started whereas Secondary Explosives are more difficult to initiate and they will form the main explosive component of, say, a munition such as the main filling in an artillery shell. Explosives for practical use are chosen to be clearly in one group or another as the use of Primary Explosives must be carefully controlled to avoid a damaging accidental initiation.

This has led to the Explosive Train (link to 6.1.1) concept in fuzes where a very small amount of Primary Explosive is physically separated from an adjacent explosive pellet until the fuze arms and brings them together. Until arming occurs an accidental initiation of the Primary Explosive will not propagate to the adjacent pellet. Both High and Low Explosives have examples of Primary and Secondary Explosives although fuzing normally is applied to warheads and not to propellants or pyrotechnics.

1.3.2.3 Military, commercial and improvised explosives

For the most part the textbook considers aspects of services explosives, however, for defence purposes there is an interest in commercial and improvised explosives. Commercial explosives (link to 11.5) for quarrying, blasting and demolition are, in most cases, quite different to military explosives in that cost is a major factor in their choice; they are produced in large quantity and generally will have a short shelf life. The only exception is in the use of certain plastic explosives in civil demolition that are similar if not identical to those employed by the services. However, there may be occasions when service personnel may wish to use commercial explosives and therefore they are included in the chapter on High Explosives with the main purpose being to show how they differ from the service explosives normally employed.

Improvised explosives (link to 16.1) are particularly relevant to certain parts of the MOD therefore a chapter is included in the textbook. These are not

explosives as normally defined as Dangerous Goods Class1 as they are often too sensitive or too unstable to be accepted as a practical explosive. However, by all other definitions they act as explosives in their ability to either cause explosion or self-sustained burning to provide incendiary effects.

1.3.2.4 Performance, safety and reliability

Explosives for defence use are normally chosen to maximise the output matched to their application but other considerations are also applied to find explosives that are safe and suitable for service use. Unlike commercial explosives, service explosives can have long storage life, experience much lower or higher temperatures or be subject to attack during operations. A balance must be made between performance requirements and the need to minimise the likelihood of inadvertent initiation through instability or physical insult while their performance must not be degraded during their storage life or operations and reliably perform as designed.

There always will be a balance between performance, safety and reliability. For example, to increase safety it may be sensible to use a very insensitive explosive; however, this may make it difficult to initiate reliably. There are some explosives that are very high energy but are quite unstable and spontaneously decompose and become useless, or worse, very sensitive and therefore hazardous in a very short time. There are vast numbers of chemicals that potentially could exhibit explosive properties but only a few have found use in practice. Some of the factors that can affect the choice of explosives for service use are given in the following sections.

1.3.2.4.1 Performance

Propellant performance is based on its ability to produce heat and gas providing high pressures that can accelerate projectiles in a barrel or provide thrust from a rocket motor nozzle. High Explosives, for some applications, also rely on gas expansion to produce blast and underwater effects (link to 9.1) but for other warheads acceleration of metal is the primary required effect (link to 8.1). High Explosives normally are chosen to optimise one effect or the other. For example, some large air delivered bombs are designed to give blast as their main output and so gas expansion is the main requirement and creation of fragments is relatively insignificant. A Shaped Charge (link to 8.4) anti-tank warhead, however, is effective through the collapse of a metal cone and production of a very high velocity metal jet with blast being insignificant in its effectiveness.

1.3.2.4.2 Ease of initiation

The ease by which an explosive can be initiated will always be a factor in the choice for particular applications. This is called the sensitiveness (link to 20.2.1) to various stimuli such as impact, friction, heat, flame and electrostatic spark when considered from the perspective of accidental initiation and sensitivity when considered from the perspective of designed initiation. Primary Explosives exhibit properties that demonstrate they are easily initiated, which is

why they are used as the first element of an explosive train (link to 6.1.1). Secondary Explosives have to be less easily initiated than Primary Explosives for their safe application although must still be capable of reliable initiation from a designed stimulus.

1.3.2.4.3 Chemical stability

Explosives are chemicals or mixtures of chemicals which can undergo further chemical reactions. There are three main concerns with the stability of explosives, the first is that the explosive chemicals themselves are unstable and begin to break down spontaneously and small quantities of decomposition products may themselves accelerate further decomposition. Secondly, there is the potential for contaminants including moisture to react with the explosive. The third issue is that of compatibility (link to 20.4.1.1.1), that is, the explosive reacting with other substances to diminish the safety or performance properties of the munition. An example of this would be the adhesive that binds a rocket propellant to a rocket motor casing which could promote decomposition of the propellant. Service explosives are required to have very long shelf lives and can be exposed to thermal extremes which can magnify these problems.

1.3.2.4.4 Physical properties

Service explosives are solid materials and the physical properties of these solid explosive materials affect their suitability for different uses. In manufacture the explosive may need to be extruded or passed through rollers where viscosity at elevated temperatures is important for example in the manufacture of rocket propellant. For High Explosives maximising density may be required to give optimum performance while brittleness in an explosive should be avoided as this makes them prone to violent response in an accident. Elasticity, coefficient of expansion and softening temperature can affect the integrity of an explosive charge and its adhesion to the munition casing, which can have negative effects on safety and performance.

1.3.2.4.5 Ease of manufacture

The manufacture of High Explosive munitions requires the explosive to be filled in to casings. This must be taken in to consideration as the filling process can influence performance, safety and cost. It has been commonplace to employ formulations based on TNT as it melts at 81 °C allowing safe melt casting. However, there are drawbacks in that TNT contracts in volume when changing from the molten state to a solid. This can produce voids and cracks in the filled munition if not carefully controlled and if the explosive charge is accelerated very rapidly, for example as the filling of an artillery shell, this can lead to accidental ignition leading to an explosion within the barrel.

Among other manufacturing considerations is the complexity of chemistry needed to create the explosive material. If many reaction steps are required this can be costly. Equally the cost of precursor chemicals will influence choice.

1.3.2.4.6 Availability and cost

Unlike commercial explosives cost has less influence on the choice of explosive although it must be understood that the overall cost is the cost of the materials and of the manufacturing processes such as filling. Usually the explosive component of a munition or weapon is a relatively small percentage of the overall costs the weapon. What is becoming important is continuity of supply for precursor chemicals or explosives used to produce formulations. A good example of this is availability of ammonium perchlorate that is a key component in composite propellant for rocket motors. Another example is the availability of cotton linters for the manufacture of nitrocellulose.

REACH is a European Union regulation concerning the Registration, Evaluation, Authorisation and restriction of Chemicals that came into force on 1st June 2007[(4)]. Its purpose is to provide a high level of protection of human health and the environment from the use of chemicals. It is already affecting explosives manufacturing processes and in future may become even more restrictive. This is likely to have a major impact on the choice of future explosives.

1.4 REFERENCES

[1] Manufacture and Storage of Explosives Regulations 2005

[2] The Explosives Regulations 2014

[3] UN Recommendations on the Transport of Dangerous Goods - Model Regulations, Eighteenth revised edition, 2013

[4] The REACH Enforcement Regulations 2013