Land Contamination:
Technical Guidance on Special Sites:
Explosives Manufacturing & Processing Sites

R&D Technical Report P5-042/TR/03

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Statement of use

This report (P5-042/TR/03) is one of a series providing technical guidance on the complexities and characteristics of Special Sites as defined under the Contaminated Land (England) Regulations 2000 for Part IIA of the Environmental Protection Act 1990. Principally this document is for use by Agency staff carrying out regulatory duties under Part IIA, however this technical guidance contains information that may be of value to other regulators and practitioners dealing with Special Sites.

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FOREWORD

Part IIA of the Environmental Protection Act 1990 sets out a regulatory regime for the identification and remediation of land where contamination is causing unacceptable risks to defined receptors. The Environment Agency has a number of regulatory roles under this regime. Where land is designated as a Special Site, as defined in the Contaminated Land (England) Regulations 2000, the Agency will act as the enforcing authority. It is expected that a similar regime will be introduced in Wales during 2001, but the reader should check whether definitions of Special Sites in the Welsh regulations are the same as in the English ones.

The Environment Agency's approach to carrying out its regulatory responsibilities is set out in its Part IIA Process Documentation, available on the Agency website (www.environment-agency.gov.uk). This documentation sets out how the Agency intends to carry out its responsibilities under Part IIA of the Environmental Protection Act 1990, which came into force in England on 1 April 2000.

Users of the Part IIA process documentation should first refer to the Part IIA Process Handbook to obtain a clear understanding of the activities involved in the Part IIA regime, and with which Agency officer responsibility for particular tasks lies. The Procedures support the individual activities, and provide detailed step by step guidance on the necessary tasks. The Procedures are supported by Internal Standards which focus on the technical and legal aspects of the Part IIA regime. Other relevant advice is provided in Agency R&D documents and technical publications and in authoritative technical materials published by others including the Department of the Environment, Transport and the Regions.

This document is one of seven technical reports that provide background information about the categories of land designated as Special Sites identified in Regulation 2 of the Contaminated Land (England) Regulations 2000. The reports focus on the complexities and characteristics of the Special Site categories, and in particular, contamination types found specifically on these sites. The reports are not intended to provide regulatory or procedural guidance, but they aim to provide technical information to assist both Agency staff and others dealing with Special Sites in carrying out their work.

In the interests of transparency and openness, Part IIA process documentation, including this series of technical reports are made available to persons outside the Agency. They have particular relevance to local authorities, SEPA, DoE NI and to those affected by regulation under Part IIA.

GLOSSARY

Definitions

‘High’ and ‘low’ explosives

The rates of combustion of explosives may vary greatly, depending not only on their composition or chemical constitution but on their physical form, their degree of confinement (for example, loose powder, compressed charge, light container, heavy shell) and the nature of the means employed to initiate their combustion. Combustion rates varying from a few centimetres per minute to 8,500 metres per second (detonation velocity) have been measured. Relatively low rates (say, up to 400-500 metres per second) are characteristic of gunpowder and 'smokeless powders', which at one time were known as 'low' explosives in contrast with the more rapidly burning 'high' explosives. (The expression 'low explosive' is not now in common use).

High explosives and their detonation

A true explosive is characterised by the fact that in its combustion process an exothermic (that is, heat-liberating) reaction wave passes through it, following and supporting a 'shock front'. This phenomenon is described as 'detonation' and the velocity of the wave is the 'velocity of detonation'.

Specific Technical Terms

Amatols	Pourable mixtures of ammonium nitrate and trinitrotoluene of widely varying compositions.
Azides	Salts of hydrazoic acid (N_3H).
Blending	The mixing of gun propellant grains or sticks to achieve regular ballistics.
Booster	Used in an explosive train between a detonator and high explosive charge (see also primer).
Cap	See detonator.
Cartridge	A general term that can have a wide range of usage. It usually refers to a package or assembly of propellant explosive although it can sometimes describe a complete round of ammunition. In commercial explosives it is a general term for an individual explosive package.
Charge	A bagged, wrapped or cased quantity of explosive without its own integral means of ignition.

Class A, B, C explosives	American classification: A: explosives which possess detonating or otherwise maximum hazard such as, but not limited to, dynamite, nitroglycerine, lead azide, blasting caps and detonator primers B: explosives which possess flammable hazard such as, but not limited to, propellant explosives, photographic flash powders and some special fireworks C: explosives which contain class A or B explosives or both components in restricted quantities.
Combining	The mixing of different explosives, stabilisers or other ingredients.
Cordite	Historical name for double base (nitroglycerine/nitrocellulose) gun propellants in the UK.
Deflagration	Reaction where materials decompose at a rate much below the sonic velocity of the material without any access of atmospheric oxygen being required. It is propagated by the liberated heat of reaction.
Detonation	A form of reaction given by an explosive substance in which the chemical reaction produces a shock wave. High temperature and pressure gradients are created in the wave front so that the chemical reaction is initiated instantaneously.
Detonator	The component within an explosive train which, when detonated, in turn detonates a less sensitive but larger high explosive (usually the booster), or when containing its own primer initiates the detonation. A cap is a similar component designed to initiate a deflagration.
Doping	The addition of a marker material to an explosive composition.
Double base	Group of gun propellants based on nitrocellulose and nitroglycerine. Usually more energetic than single base propellants.
Drying	Drying of explosives or ingredients in a drying room or over a dessicant to facilitate the removal of solvents (used in some mixing processes) or to achieve a specified moisture level.
Explosion	Chemical reaction or change of state effected in an exceedingly short period of time with the generation of a high temperature and generally a large quantity of gas. An explosion can produce a shock wave in the surrounding medium. (See also detonation and deflagration).
Explosive train	A train of combustible and explosive elements arranged in order of decreasing sensitivity. The explosive train accomplishes the

	controlled augmentation of a small impulse into one of suitable energy to actuate the main charge.
Figure of insensitiveness (F of I)	A figure determined by a Rotter Impact Test which is a measure of the sensitiveness of an explosive to an impact. The higher the result, the less sensitive the explosive.
Flare	Pyrotechnic device designed to produce a single source of intense light.
Flash over	Sympathetic detonation/daflagration from a cartridge to another one adjacent to it.
Fuel	Any substance capable of reacting with oxygen and oxygen carriers with the evolution of heat.
Fuze or fuse	Device with explosive or pyrotechnic components designed to initiate a train of fire or detonation.
Fuseheads	Components within a detonator.
Gains	Small explosive charge that is sometimes placed between the detonator and the main charge to ensure ignition.
GAM	Gelatinised Azide Molybdenum.
Glazing	The addition of a surface lubricant coating usually to propellant grains. A typical glazing agent would be graphite.
Hangfire	The non-ignition or partial ignition of a propellant charge or cartridge within a gun chamber. A very dangerous phenomenon.
Incendiary	A highly exothermic composition or material that is primarily used to start fires.
Incorporators	Used in the pour filling of high explosive munitions. Usually TNT mixtures are melted in an incorporator to form a slurry which is then poured into a shell casing and allowed to solidify.
Initiating (primary) explosives	Explosives that can detonate by the action of a relatively weak mechanical shock or by an electric current used to initiate the main explosive charge.
Initiation	To set off explosive charges. To detonate.
Magazine	Any building or structure approved for the storage of explosive materials. Also a removable case holding several rounds or cartridges used in some types of firearms.

Manufacturing terms	Common terminology used for explosive manufacturing processes. Include characterising, coming, combing, drying, dopeing, glazing, incorporating, milling, mixing, nitrating, pressing, rumbling, stabilising, steeping, stoving and washing.
Milling	The reduction in size (using a grinding mill) of explosive compositions or explosive ingredients to a specific particle size.
Mixing	The combination of a number of ingredients to form an explosive.
Motor	Term for a propellant gas generator or rocket.
Nitrating	The process by which hydrocarbons are nitrated using nitrating agents. For example the nitration of toluene using nitric acid (and sulphuric acid) to form trinitrotoluene (TNT).
Nitrocotton/NC	Nitrated cellulose material – cotton, wood pulp or paper.
Oxidiser	Chemical or mechanical incorporation of oxygen into the explosive reaction/material.
Pellets	Explosives in the form of round shaped granules, e.g. TNT. Also refers to small spherical charges of tetryl.
Percussion caps	Serve as primers of propellant charges.
Pressing	The compaction of explosive powders to form pellets, filled caps, detonators and the press filling of high explosives.
Primary explosive	A sensitive explosive which nearly always detonates by simple ignition from such means as spark, flame, impact or electrical discharge.
Primer	A primary initiating device to produce a hot flame (also see booster).
Propellant	Explosive material with a lower rate of combustion (deflagration), solid or liquid that will burn smoothly at uniform rate after ignition without depending on interaction with atmosphere.
Rolling	The gelatinisation of certain propellants using heated rollers.
Secondary explosives	Explosives in which the detonation is initiated by the detonation impact of a primary explosive.
Shell	A projectile containing an explosive charge intended to burst it, fired from a gun or rocket launcher.
Shock wave	Intense compression wave produced by the detonation of explosives.

Sieving	The sieving of explosives is undertaken in order to achieve a known particle size. Also used in propellant manufacture to remove fuses.
Single base	Collective term for gun propellant compounds based on nitrocellulose with small amounts of stabiliser, plasticiser or coolant added.
Small arms ammunition	Ammunition with a calibre up to 20 mm.
Stabilisers	Compounds which when added in small amounts to other chemical compounds or mixtures impart stability to the latter.
Steeping	Where an explosive or ingredient is submerged in a liquid in order to either coat it, add a further ingredient, change its properties or to remove a solvent.
Stoving	The process of heating to cure paints, lacquers, or thermosetting Polymer Bonded Explosives (PBX).
Sympathetic detonation	The initiation of an explosive charge without a priming device by the detonation of another charge in close proximity.
Tracers	Slow burning pyrotechnic compositions used in tracer bullets, signalling charges, tracer rockets etc. Colour is due to the presence of added salts such as sodium, barium, and strontium etc.
Triple Base	Group of gun propellants based on nitrocellulose, nitroglycerine and nitroguanidine.
UXB	Unexploded bomb. Sub-group of UXO.
UXO	Unexploded ordnance.
Washing	The purification of explosive compositions after synthesis in order to remove impurities.

1. INTRODUCTION

1.1 Background

This report is one of a series of technical guidance documents relating to Special Sites that are part of the statutory regime for contaminated land introduced by the implementation of s.57 of the Environment Act 1995 that added Part IIA into the 1990 Environmental Protection Act (EPA 1990). The application of this primary legislation is via the Contaminated Land (England) Regulations 2000 and the accompanying DETR Circular 02/2000.

This report provides technical information relevant to explosives manufacturing and processing sites.

Within the Contaminated Land (England) Regulations 2000 this category of Special Site is defined as:

- *land on which any of the following activities have been carried on at any time ... the manufacture or processing of explosives*

This report serves as a supplement to, and should be used in conjunction with, the following Environment Agency documents to provide supporting information relevant to the discharge of Environment Agency responsibilities for Special Sites:

- Part IIA EPA 1990 Process Documentation ; and

- DETR/Environment Agency. CLR11. Model Procedures for the Management of Contaminated Land (in preparation).

In addition, the reader is directed to other documents published by the Environment Agency, the DETR and others in the references and bibliography section of this report.

1.2 The Role of the Environment Agency in Relation to Special Sites

Full details of Environment Agency regulatory roles, responsibilities and procedures for dealing with Special Sites are provided in the Part IIA process documentation, and only a brief overview is included here.

The principal regulators for Part IIA (EPA 1990) are Local Authorities. The Environment Agency has an important complementary regulatory role with specific responsibilities including the provision of information and advice, and acting as enforcing authority in relation to Special Sites.

Local Authorities are responsible for identifying land in their areas which meets the statutory definition of contaminated land under Part IIA (EPA 1990). In doing so, Local Authorities will seek information from the Environment Agency, and advice in respect of pollution of controlled waters. Part IIA (EPA 1990) provides for certain land that meets the definition of contaminated land to be designated as a Special Site, if it meets one of a number of categories of land prescribed in the Contaminated Land (England) Regulations 2000. In cases where a

Local Authority believes that land, if found to be contaminated land, would subsequently be a Special Site, it will normally ask the Environment Agency to carry out a site inspection on its behalf, prior to determination of that land as contaminated land. However, the responsibility for formal determination of any land as contaminated land remains with the Local Authority in all cases.

Once land has been determined to be contaminated land, and where the Environment Agency and Local Authority agree (or the Secretary of State decides) that the land is also a Special Site, the Environment Agency will take over the role of enforcing authority from the Local Authority. Remediation of the site may include further investigation and assessment (assessment action), action to remedy the unacceptable risks identified (remedial treatment action) or monitoring (monitoring action). The Agency is responsible for maintaining a public register of regulatory action for Special Sites.

1.3 How to Use this Technical Guidance

This series of reports on Special Sites is primarily intended to provide Environment Agency Officers with the specialist technical information required when dealing with Special Sites under Part IIA (EPA 1990). Thus, every effort has been made to minimise the overlap with other guidance on generic aspects of contaminated land identification, assessment and management. In practice, it is likely that the reports will also prove useful to Local Authority officers, and others, when dealing with these types of sites.

The reports focus on the categories of land identified by Regulation 2 of the Contaminated Land (England) Regulations 2000. Separate guidance has been developed for those sites that are Special Sites by virtue of the seriousness of pollution of controlled waters (defined by Regulation 3 of the Contaminated Land (England) Regulations 2000).

The information contained in each report is arranged and presented so that it can easily be drawn upon when using other relevant guidance such as the Part IIA EPA 1990 process documentation. It begins with background information on, for example, the industrial process and facility description; further sections describe key issues that should be considered during the characterisation, assessment, remediation and validation stages for each category of Special Site. References and a bibliography are also provided, together with a glossary of terms (both general contaminated land industry terms and also those specific to the individual technical field).

The format adopted in the report aims to assist the reader in the practical use of the technical information it contains by the inclusion of, where appropriate, selected checklists, diagrams, photographs, case studies and the highlighting of key technical information. In addition, at the start of each of the sections, a list of the key questions is included that highlight the issues covered by the section. The key issues that are addressed in the various sections of this report are as follows.

SECTION 2: INDUSTRIAL PROCESS/FACILITY DESCRIPTION

1. What constitutes an explosive?

2. What sites may have explosives present?

3. What is the likely distribution of contaminants within the ground across the site?

4. How can the most significant contaminative processes which were undertaken on the site be identified and located?

5. Should other processes/contaminants be suspected which are not obvious from available records?

6. How are (or were) waste explosives managed?

SECTION 3: PHYSICAL AND CHEMICAL CHARACTERISTICS OF CONTAMINANTS

1. What contaminants are likely to be present?

2. What are the main chemical and physical characteristics of the principal contaminants?

3. How do the principal contaminants behave in the environment?

SECTION 4: SITE CHARACTERISATION

1. Which additional information sources should be used for a desk study?

2. What are the main differences from a conventional contaminated land investigation?

3. Are special sampling and sample handling procedures required?

4. What should be analysed for and when?

SECTION 5: SITE EVALUATION

1. What are the probable pollutant linkages that should be assessed?

2. Which of these pollutant linkages are likely to be the most significant?

3. Are there appropriate ‘trigger/guideline’ values that can be used to benchmark the investigation data?

4. When is it appropriate/inappropriate to apply conventional risk assessment methods to this category of special sites?

SECTION 6: REMEDIATION ASPECTS

1. Which remediation technologies could be appropriate?

2. What are the main constraints and advantages to each of the applicable remediation technologies/engineering methods?

3. What are the anticipated perception/community impacts of the remediation technologies?

4. Are the technologies compatible with site reuse?

5. How can the remediation process be validated?

SECTION 7: HEALTH AND SAFETY

1. What legislation specific to explosives is relevant?

2. What working methods should be adopted for explosives sites?

3. What specialist equipment is required?

1.4 Risk Communication Issues

Public awareness of contamination issues, together with the general perception of associated risks and the potential for harm (in the conventional sense) has increased during the 1980s and 1990s. Useful guidance with respect to risk communication issues can be found in Environment Agency R&D Technical Report P142 "Communicating Understanding of Contaminated Land Risks" (SNIFFER 1999).

1.5 Linkages Between the Guidance Reports and the Special Site Categories

Many of the Special Site categories are likely to include technical aspects that are incorporated into more than one of the seven individual guidance reports. A matrix showing the links that may be relevant between the guidance reports and the Special Site categories is given below in Table 1.1.

Table 1.1 - Linkage between guidance reports and Special Site categories

Special Sites Categories *(for full definitions see the Contaminated Land (England) Regulations 2000)*	**Reports in This Series of Particular Relevance to Each Special Sites Category**						
	P5-042/TR/01 MOD Land	*P5-042/TR/02 Chemical Weapons*	*P5-042/TR/03 Explosives Manufacturing*	*P5-042/TR/04 Acid Tar Lagoons*	*P5-042/TR/05 Petroleum Refineries*	*P5-042/TR/06 Nuclear Establishments*	*P5-042/TR/07 Prescribed Processes Designated for Central Control*
Regulation 3 Land	land to which Regulation 3 applies is dealt with separately from this series of reports						
Acid Tar Lagoons				√	√		
Petroleum Refineries				√	√		√
Explosives Manufacturing or Processing Sites	√	√	√			√	√
Prescribed Processes Designated for Central Control			√		√		√
Nuclear Licensed Sites	√	√	√			√	
Current Naval, Military and Air Force Land	√	√	√		√	√	
Chemical Sites	√	√	√				
AWE Sites	√		√			√	
S.30 of the Armed Forces Act Land	√		√			√	

2. INDUSTRIAL PROCESS/FACILITY DESCRIPTION

KEY QUESTIONS COVERED IN THIS SECTION

1. What constitutes an explosive?
2. What sites may have explosives present?
3. What is the likely distribution of contaminants within the ground across the site?
4. How can the most significant contaminative processes which were undertaken on the site be identified and located?
5. Should other processes/contaminants be suspected which are not obvious from available records?
6. How are (or were) waste explosives managed?

2.1 Scope

This section presents an overview of the key aspects of sites where explosives have been manufactured, stored or processed, the types of sites that may have contamination of this nature, and their distribution and extent in the UK. It also provides a description of the main processes and activities that have occurred on explosives manufacturing and processing sites that are likely to have resulted in ground contamination. The processing of explosives covers the chemical manufacture, mixing, filling and packing of explosives into ammunition or any explosive device. Whilst explosives manufacturing and processing sites can contain a range of contaminants, this section mainly concentrates on the contaminants of concern which are specific to such sites – namely the explosives (and associated devices), their precursors, breakdown products and waste disposal.

A key reference for this section is the relevant DoE Industry Profile Chemical Works: Explosives, Propellants and Pyrotechnics Manufacturing Works (see references DoE 1995a for full details).

2.1.1 What constitutes an explosive

In its widest definition, an explosive is any material which can be made to detonate or deflagrate. In general terms an explosion is the result or effect of a chemical reaction or change of state effected in an exceedingly short time period, resulting in the generation of a high temperature and large quantity of gas. In a detonation the reaction produces a supersonic shock wave which propagates the explosion. In a deflagration the reaction rate is below the sonic velocity. A deflagration is propagated by the liberated heat of the reaction. The term explosion covers both detonation and deflagration.

The term "explosive" covers a wide range of substances and devices. Explosions can be effected from a wide range of substances and conditions (e.g. hydrocarbon vapour - air mixtures). This category of Special Sites relates to sites where explosive substances or devices are manufactured (for military or civil use). Such sites are controlled by specific legislation, for example the Explosives Act (1875), which will be replaced by the Manufacture and Storage of Explosives Regulations (expected 2002) and the equivalent legislative framework covering MoD explosive facilities. This report concentrates on the explosive substances and devices manufactured, processed or stored in such facilities.

Explosives are classified according to the United Nations (UN) Classification system and UN Serial numbers, the basic classification being:

- UN Classification 1.1

– Generally high explosives or explosives which can burn to detonation;

- UN Classification 1.2

– Explosives or ammunition that, on burning, will give rise to fragments and projectiles;

- UN classification 1.3

– Explosives that will not burn to detonation but can result in deflagration and flame jetting effects;

- UN classification 1.4

– Explosives that are likely to produce only localised effects on burning (i.e. not detonation or deflagration). These are often pyrotechnic compositions.

2.1.2 Overview of explosives manufacturing and storage

General points regarding sites where explosives were/are manufactured, processed or stored include the following:

- the majority of explosives sites in the UK were built for either military or commercial use. Military explosives sites were mainly involved in explosive substance manufacture or ammunition filling or manufacture. Commercial explosives sites were in the main involved in manufacturing commercial blasting explosives and related devices as well as fireworks;

- numerous explosives sites were built or recommissioned during both World Wars and to a lesser extent during the Korean War. Most of these sites were closed hurriedly after these wars. Consequently many have been utilised for various other purposes, including military/other government, formerly nationalised industries (e.g. power generation, telecommunications), industrial estates (often involving local authorities). Conversely, some still lie derelict or have been converted to agricultural use;

- a wide range of non-explosive contaminants may be encountered on many of these sites dependent on the processes involved. These are not discussed in detail in this report. The reader is referred to the relevant Industry Profile when investigating such sites (DoE (1995b));

- establishing the period of operation of a particular site may assist in determining the types of explosives which could be present in the soils;

- lack of availability of records concerning military explosives sites is a major problem (as with other MoD sites). Information relating to site layout, processes and materials produced (especially at R&D sites) may not be available. The main reason for this is a past desire to keep such sites secret, especially during war time (e.g. military and some strategic commercial explosives sites were not shown on OS maps until the 1980s). Information concerning these sites was often lost or dispersed after the wars or as a result of reorganisation of Government departments, or in the case of commercial sites as a result of mergers or takeovers;

- whilst a former explosives site may have been used for other purposes, the decommissioning and remediation standards employed in the past may not meet present day requirements.

2.2 Distribution and Extent of Explosives sites in the UK

2.2.1 Key points

- Most explosives sites are large in area - often many hundreds of hectares - and originally sited away from centres of population. However, over the years, many have become surrounded by urban development or only a small part of the former factory is still recognisable;

- at the end of WWII there were some 30 large scale manufacturing sites and 50 to 60 smaller facilities. In addition there were of the order of 2,000 licensed explosives sites on which the filling and storage of munitions was carried out;

- there is no particular concentration of explosives sites in any one area of the country. Post 1900 military explosives sites were deliberately dispersed throughout the UK to minimise the effects of enemy bombing. However the larger manufacturing facilities needed access to large numbers of employees and required good rail links;

- many of the older commercial explosives sites may have been used for military purposes during the World Wars and may have continued to conduct government contracts for military use of explosives.

2.2.2 Uncertainties

- Historical records of military explosives sites (and commercial sites undertaking Government defence related work) can be very difficult to obtain from normal sources. Certain information may even be misleading (e.g. omission of military related explosives sites from OS maps implies continuation of the site's pre-explosives use – often agricultural use);

- information may be found in public records, however much is retained in various MoD or private company sources. Many of these records are incomplete due to loss or destruction during closure of sites and various company or Government department reorganisations;

- even when records seem to be relatively complete, variations in working practices need to be addressed (e.g. disposal of wastes and reject ammunition). In addition records of sensitive operations or processes may have been security classified and the records stored separately. Some records may still have a Government classification;

- a few explosives sites have a very long history with several generations of processes and development. It is often not clear what remains of these previous processes – frequently the new operations were built on top of the old foundations, which may have resulted in the trapping of previous contamination.

2.2.3 Unidentified sites

For some sites, it may be difficult to identify their former use as an explosives manufacturing site. This is often the case with sites that were either demolished or passed back into civilian hands many years ago, such as those which were closed after the end of the World Wars. Box 2.1 provides some examples of typical scenarios relating to unidentified sites.

Box 2.1 Unidentified Sites

Scenario 1

A landowner had held a site of a few hundred hectares in its land bank for many years. The site was mainly used for agriculture and forestry. The County series and OS maps indicated that the site had been fields and woodland for well over 100 years. The landowner was aware of a few building foundations on some parts of the site. A local inhabitant informed the landowner that he understood that the site had been a WWI munitions factory. This was the first information that the landowner had received regarding former use of the site.

Research showed that the site had indeed been a major munitions filling factory during WWI. Although in a semi-rural setting and poorly served by road, the site was close to an existing railway. Information including layout plans were found which enabled a good picture to be built up of land use and potentially contaminative processes. This enabled a focussed preliminary site investigation and subsequent risk assessment to be carried out.

Scenario 2

A geotechnical study was commissioned that covered an area of farmland to assist the design of an improved drainage scheme. As members of the drilling crew were setting up, the farmer informed them that, according to his father, they were on the site of a WWI explosives factory. The search of the usual record sources had indicated that the land had always been used for agriculture. However, site reconnaissance by a trained observer revealed rectangular features in the ground profile in one area of the fields.

Subsequent research showed that the farmer was correct and that a factory manufacturing military explosives had operated there during WWI.

2.3 Key Site Features

The principal types of manufacturing or processing sites where contamination by explosives may be encountered are as follows:

- military explosives factories;
- commercial explosives factories;
- fireworks and pyrotechnics factories;
- ammunition filling and assembly factories;
- explosive depots or magazines;
- explosives research & development (R&D) facilities.

Within each of these types of sites explosives contamination or other significant contamination risks may be associated with the following process areas:

- bulk chemical storage;
- chemical plant;
- filling & assembly;
- magazines;
- lead smelting (ancillary process);
- casting;
- laboratories;
- railway networks;
- water features (e.g. ponds or canals);
- disposal sites (e.g. historical waste tips containing various waste materials);
- burning grounds;
- firing ranges (sometimes referred to as testing ranges or stations);
- on-site heat & power stations and electrical substations;
- engineering workshops;
- laundries.

Table 2.1 provides an initial indication of which of these features is likely to be of concern on each of the site types:

Table 2.1 – Features likely to be of concern on different site types

Feature	Site Type				
	Military Explosives Factories	**Commercial Explosives Factories**	**Fireworks & Pyrotechnics Factories**	**Ammunition Fill & Assembly Factories**	**Research & Development Factories**
Bulk Chemical Storage	**	**	-	-	-
Chemical Plant	**	**	*	*	**
Filling & Assembly	-	*	**	**	*
Magazines	**	**	**	**	*
Lead smelting	-	-	-	*	-
Casting	-	-	-	*	-
Laboratories	**	**	**	**	**
Railway Networks	**	*	*	**	*
Ponds or Canals	*	*	-	*	*
Disposal Sites	**	**	*	**	**
Burning Grounds	**	**	**	**	**
Firing Ranges/testing ranges	-	*	*	*	*
Heat & Power Stations	**	**	-	**	*
Engineering Workshops	**	**	*	**	**
Laundries	**	*	*	**	*

*	Sometimes present
**	Usually present
-	Absent/usually absent

Each of these categories is described in greater detail in the following sections.

2.3.1 Bulk chemical storage

Key points relating to bulk chemical storage on explosives manufacturing sites include:

- nitric and sulphuric acids are reagents in most explosives manufacturing processes. Although unlikely to be retained in the soil, bulk acid leakage may erode building foundations and has been known to create swallow holes in limestone and chalk areas. Additionally waste acids, which may have been deposited in the soil, often contain potentially toxic nitro-bodies. Examples of these are:

    - dissolved nitroaromatic compounds in TNT waste acid (these are by-products of the chemical process);

    - nitroglycerine waste acid containing dissolved or suspended nitroglcerine;

- the precursor chemicals used to manufacture explosives can present a contamination risk. The chemicals used in the explosives manufacturing processes on the site should be researched.

2.3.2 Chemical plant

Key points relating to chemical plant on explosives manufacturing sites and R&D facilities include:

- chemical effluents and spillages (including explosive substances) were not always treated or well controlled. Major spillages of explosives into soil around chemical plant have been known. This has occurred especially where the explosive during manufacturing or processing was a liquid, in a slurry or in solution. In particular, drains may contain explosive residues and these can be a source of ground contamination where these drains have leaked;

- emergency discharge often formed part of fail safe systems in the event of an emergency;

- explosives contamination of any remaining buildings, foundations and process plant should be suspected;

- process drains were sometimes overhead (e.g. supported lead gutters);

- the possibility of mixtures of chemical compounds being found in effluent streams should be considered and whether there is any chance of these compounds reacting with each other;

- it is important to identify the specific explosives manufactured and the approximate dates to understand the possible processes employed on the site.

2.3.3 Filling and assembly

Key points relating to filling and assembly (may sometimes be referred to as cartridging) on explosives manufacturing and R&D facilities sites include:

- explosives contamination may be localised – near to the buildings or areas where the explosives were stored or processed. However bulk contamination around ammunition filling buildings, close to drains or even under building foundations, has been known;

- filled devices can often deteriorate and become more sensitive with time (e.g. open copper detonators);

- airborne explosives dusts can accumulate in the cracks, fabric and recesses of buildings and can be found under floors, behind walls etc.

- again it is important to understand the particular processes and their layout to assess the potential contamination risk;

- the risk from buried explosives devices and ammunition must always be considered in all ammunition filling and assembly sites. These devices can be found in a wide range of forms including:
    - very small but highly dangerous detonators and initiators – both commercial and military;
    - small arms ammunition (bullets);
    - fuses and primers;
    - cord explosives (commercial and military use);
    - various calibres of ammunition in a range of designs;
    - rocket motors;
    - bombs and mines of various sizes and designs.

With thousands of different types, it requires specialist knowledge to identify an explosive device. Consequently, on an explosives contaminated site, all items which are not readily identifiable should be assumed to be of an explosive nature until proven otherwise by a specialist. Risks from such devices should always be assessed by an expert.

It is also important to understand whether explosive devices were produced, stored or used on a site.

2.3.4 Magazines

Key points relating to magazines on explosives manufacturing and R&D facilities sites include:

- although bulk explosives or munitions would have been stored in such buildings, the materials were normally packaged which generally minimised the risk of spillages. However, localised contamination from inspection or maintenance operations must be considered. Where ammunition was stored there is a possible risk of buried munitions;

- leakages can occur from faulty or out of date products;

- contamination in and around magazine buildings is likely to be much less than that expected in and around process buildings;

- damaged finished product may be found within a short distance of walkways and accesses.

2.3.5 Lead smelting and casting

Key points relating to lead smelting and casting on explosives manufacturing and R&D facilities sites include:

- Up until recent times lead was a widely used material in explosives manufacturing and processing including lining of acid vats, flooring for certain explosives buildings, pipework and even guttering for nitroglycerine transfer between buildings. Thus there were opportunities for lead to come in contact with explosives or be corroded by acids.

- Many explosives manufacturing sites had specialist lead workshops for production and repair of lead piping and sheet. On such sites, lead was often decontaminated by melting (thus decomposing any explosives) and cast into ingots for resale.

2.3.6 Laboratories and inspection areas

Key points relating to laboratories on explosives manufacturing and R&D facilities sites include:

- although the quantities of explosives within laboratories were usually small, explosives contamination can, in particular, be expected within effluent drains and any local disposal areas. In some laboratories, explosives samples have been known to have been stored in containers which are not normally associated with explosives;

- a wide range of chemicals was frequently used in laboratories. In the past these chemicals were not always well controlled. Other items known to have been found around such areas include explosive devices, ammunition and even X-ray sources.

2.3.7 Railway networks

Railway networks were historically used on many explosives sites. Key points relating to internal railway networks on explosives manufacturing and R&D facilities sites include:

- both standard gauge and narrow gauge networks may have been present (narrow gauge tended to be used for internal rail transportation and often has a higher associated risk (from spillages etc.) than standard gauge as temporary, lower quality packaging was frequently employed. Historical narrow gauge networks exhibit similar features to standard gauge, however width of track will be correspondingly reduced;

- explosive spillages are often associated with such networks and has been known to have become mixed with rail ballast and surrounding soil – especially at loading points, bends and junctions;

- in some sites boiler ash was routinely used as railway ballast.

2.3.8 Water features (e.g. ponds or canals)

Key points relating to ponds or canals on explosives manufacturing and R&D facilities sites include:

- any ponds or former ponds or other water features are candidates for explosive related contamination. Nitroglycerine (NG) and nitrocellulose (NC) effluents were, by design, drained into ponds to allow any suspended NG or NC to settle out. In some facilities the NG ponds were routinely detonated to destroy any traces of explosive. However other ponds have often been used as unauthorised disposal areas for explosives and reject explosives devices including rounds of ammunition;

Box 2.2 Scenario

A former commercial pyrotechnic and rocket factory in the SE of England contained a pond in which hundreds of explosive devices (some apparently inert) had been dumped over many years. After closure, during which time parts of the site became accessible to the general public, the pond was drained. As the mud dried out over time, a number of suspect devices were revealed in the pond bottom.

- canals were used in many old explosives sites (>100 years old) as a mode of transport within the site. Explosives spillages frequently occurred and were allowed to accumulate on the canal bottom. In addition when canals were in-filled, the material used may have contained contaminated wastes or demolition rubble from explosive contaminated buildings;

- soakaways were often used in the past for site drainage and so can present possible contamination sources.

2.3.9 Disposal sites

Key points relating to disposal sites on explosives manufacturing and R&D facilities sites include:

- until the last decade or so the general practice on explosives sites was to retain and dispose of all wastes on site. Therefore all explosives sites may contain areas where wastes were tipped. A wide range of contaminants can be present including explosives and explosive devices. Some sites have been found to contain large quantities of waste materials accumulated over many years.

2.3.10 Burning grounds

Key points relating to burning grounds on explosives manufacturing, processing and R&D facilities sites include:

- burning grounds are routinely used on explosives sites for the destruction of explosive wastes, explosive devices and explosive contaminated materials and equipment. Various hydrocarbon fuels may have been stored or used on the burning grounds;

- residual explosive contamination (including explosive fragments) is generally present in soils around burning grounds. In addition a range of other contamination including heavy metals and fuels is often present;

- ash from burning operations may contain explosive residues.

2.3.11 Firing ranges

Key points relating to firing ranges on explosives manufacturing and R&D facilities sites include:

- test or firing ranges are not generally found on explosives manufacturing sites although they may be present on some sites. They are usually associated with ammunition filling factories and certain pyrotechnic factories. Explosives and propellant residues together with misfired rounds are often found around the firing points. Other contaminants are dependent on the items being tested;

- firing butt sands may contain metal projectiles (live and inert) and metal fragments. Lead contamination is, in particular, associated with small arms firing ranges;

- discarded ammunition may be present anywhere within the firing range area.

2.3.12 Heat and power stations

Key points relating to heat or power stations on explosives manufacturing and R&D facilities sites include:

- such plants are frequently integral parts of larger explosive sites. They were often coal fired. Some sites may contain large quantities of boiler ash used or deposited on site over many years. Asbestos contamination may also be particularly prevalent in these areas resulting from insulated plant and pipework.

2.3.13 Engineering workshops

Key points relating to engineering workshops on explosives manufacturing and R&D facilities sites include:

- explosives contamination in association with conventional contamination cannot be discounted within such areas.

2.3.14 Laundries

Many explosives manufacturing sites had their own in-house laundries to clean the specialist workwear. Explosive residues have been known to accumulate in such buildings and associated drains.

2.4 Summary of Principal Potential Pollutant Linkages

Table 2.2 illustrates the most common pollutant linkages associated with explosive manufacturing sites. However as the range of explosive processes found in the UK is large, it is important to build an understanding of the particular processes found on any such site and if in doubt seek expert advice or conduct specialist research.

Table 2.2 - Principal potential pollutant sources, probable contaminants and processes

PRINCIPAL POTENTIAL POLLUTION SOURCE	ASSOCIATED CONTAMINANTS	PROCESS/ACTIVITY
Harm		
Explosives contaminated shallow soils or building fabric – acute hazard to humans (fire or explosion)	Wide range of explosive compounds in high (localised) concentrations – especially under locally dry conditions. e.g.: spillages of TNT from filling of large calibre shells	1. Explosives chemical plant 2. Ammunition and other explosive device filling 3. Disposal areas
Explosives contaminated shallow soils or building fabric - toxicological hazard to humans	Wide range of explosive compounds in lower concentrations (e.g. <1%). e.g.: unburnt explosive residues within the soils of burning grounds	1. Any of the processes where explosives are used including burning grounds and disposal areas
Explosives contaminated underground utilities or deep soils – possible threat to humans especially maintenance or redevelopment workers	Explosives in the form of liquids, slurries or in solution	1. Any process involving the movement/discharge of explosives in pipelines (e.g. bulk liquid transport systems) and drains 2. Any process where there is a pathway for explosives to contaminate deeper soils
Buried munitions – acute threat to humans	Wide range of ammunition and related devices	1. Ammunition assembly and filling 2. Disposal areas
Asbestos release to atmosphere – threat to humans	Asbestos from buildings, services or soil	1. Any process involving heat including steam lines 2. Building insulation material 3. Pyrotechnic manufacture
Explosives threat to controlled waters		
Contaminated soil	NG plus related nitroglycerols, Picric Acid and under certain conditions Tetryl and TNT related compounds, any explosive in solution	1. Manufacture of NG or nitroglycerols (DNAPLs) 2. Manufacture of Picric Acid or Tetryl (Picric Acid is soluble in water) 3. TNT processing – 'red' waters 4. Any solvent recrystalisation process
Drainage systems	As above, plus any explosive slurry or residue	1. As above plus explosive processes where slurries are involved

2.5 Typical Site Layouts

As many explosives manufacturing sites occupy large areas, it is important to research and understand the distribution of contaminative processes understood to be present on any specific site. The site layout is a function of :

- the type of explosive site - as described in Section 2.3;
- the history of the site (e.g. many WWII built military explosives sites were based on a common design);

- the local geography.

Common features include:

- clusters of relatively small buildings that are much more widely separated than normal factory units;

- buildings may have unusual concrete structures (e.g. bunkers) or be surrounded or partly covered by earth mounds;

- in certain sites (e.g. firework or pyrotechnic factories) buildings may be particularly small and of very light structure including all wooden structures;

- buildings may be linked by only paths or narrow roadways of an unusual/unconventional layout. Alternatively narrow or standard gauge railway may be the only obvious transport link between buildings;

- explosive and ammunition filling and assembly factories built using a common design may show very similar building layouts. Site records may even show common building numbering and process section numbering. An experienced researcher can use this information as evidence of the process layouts.

A series of plates illustrating particular aspects relating to the production of explosives is contained within Appendix 1. Plate 1 shows the layout of part of a typical explosives manufacturing site, Plate 2 shows cordite propellant in the ground and Plate 3 shows the typical layout of a Picrite factory.

3. CHEMICAL AND PHYSICAL CHARACTERISTICS OF PRINCIPAL CONTAMINANTS

KEY QUESTIONS ANSWERED IN THIS SECTION

1. What contaminants are likely to be present?
2. What are the main chemical and physical characteristics of the principal contaminants?
3. How do the principal contaminants behave in the environment?

3.1 Scope

This section presents information relating to the types of explosives and explosive devices which may be encountered at the sites discussed above. It includes information relating to their chemical and physical form, toxicity and behaviour in the environment. Further technical details which support the summary information presented within this section are given in Appendix B.

Section 3.2 describes the main categories of explosives. Section 3.3 contains information on the principal raw materials involved in explosives manufacturing whilst section 3.4 contains details of explosives related breakdown products and the factors which influence degradation in the environment.

3.2 Principal Explosive Contaminants

There are various ways of categorising explosives e.g. by their function (high explosives, initiators, propellants, pyrotechnics etc.) or by UN Hazard Class (see Section 2.1.1.). The approach used here is to classify explosives according to their chemical composition. R Meyer & J Kohler (1993) is a useful reference.

3.2.1 Organic explosive compounds

The 11 most commonly encountered organic explosive compounds are:

TNT	2,4,6- trinitrotoluene;
RDX	cyclotrimethylene trinitramine;
HMX	cyclotetramethylene tetranitramine;
PETN	pentaerythritol tetranitrate;
picric acid	2,4,6- trinitrophenol;
tetryl	trinitrophenylmethylnitramine;
NC	nitrocellulose;
NG	nitroglycerine;
EGDN	nitroglycol;
picrite	nitroguanidine;
HNS	hexanitrostilbene (additive for explosives).

Table B.3 in Appendix B, provides details of the chemical structures, official technical terms and the commonly used alternative names for the above 11 commonly encountered explosives. It should be noted that many explosives are complex mixtures of these and other compounds. These mixtures have their own technical names, many of which have come into colloquial use (e.g. cordite, Comp B, PE4, Amatol), standard references such as R Meyer & J Kohler (1993) detail many of these technical and colloquial terms. As an example NG and EGDN are often used in combination as a low melting point form of NG.

3.2.2 Metal salt explosives

In addition to the organic explosives there are a number of inorganic compounds with explosive properties. Many of these substances are highly sensitive and will detonate with the slightest movement. They are commonly used as initiators. Examples of inorganic explosives are:

- lead azide;
- lead styphnate;
- lead dinitroresorcinate (LDNR);
- lead azotetrazole;
- lead monoresorcinate (LMNR):
- mercury fulminate.

In some cases the above compounds were mixed with each other or different compounds to produce explosives with better performance. This list is by no means exhaustive and there are a wide range of metal compounds which have been used as explosives in the past.

3.2.3 Pyrotechnics

This is a collective name for a wide range of lower power explosives or explosive devices used in a wide range of applications – including commercial fireworks. Applications include:

- delay compositions;
- primer compositions;
- igniter compositions;
- signal/flare compositions;
- tracer compositions; and
- smoke compositions.

These materials can be composed of a variety of compounds dependent on the type of pyrotechnic in question and on the colours of smoke of flares required (see Appendix B.5 for examples).

3.2.4 Chlorate and perchlorate based explosives

These explosives consist of intimate mixtures of hydrocarbons (e.g. waxes or polymeric binders and rubbers) as the fuel, and metal chlorates, perchlorates or ammonium perchlorate as the oxidiser. Certain commercial mining explosives were chlorate or perchlorate based explosives. However, the main current application of this family of explosives is in composite rocket motors (e.g. space rockets) in which ammonium perchlorate is incorporated into a rubber composition. Although technically a powerful oxidising agent, ammonium perchlorate can under certain conditions detonate.

3.2.5 Ammonium nitrate based explosives

Ammonium nitrate is a major ingredient in fertilisers. When mixed with a fuel, however, the ammonium nitrate mixture becomes a powerful explosive. Around WWI, amatol compositions (mixtures of ammonium nitrate and TNT) were widely used as military high explosives. However, ammonium nitrate explosives are now mainly used as commercial explosives. ANFO (ammonium nitrate – fuel oil) slurry and emulsion explosives are all mixtures of ammonium nitrate and fuels. Some contain various additives to modify physical properties. These explosives can be supplied in packaged form or can be formed by mixing the ingredients just prior to use. In the latter instance, only the raw materials are likely to be found on sites or as a contaminant in the ground. Ammonium nitrate can under certain conditions detonate without a fuel being present. Slurry and emulsion explosives often contain other additives as sensitisers e.g. aluminium powder.

3.3 Raw Materials

Many of the raw materials used in explosives manufacturing processes may also be explosive and/or toxic. Table B.4 in Appendix B provides details of the more important raw materials/precursors used in the manufacture of the explosives discussed above. Table B.5 in Appendix B provides examples of the types of ingredients found in pyrotechnic compositions.

3.4 Breakdown Products

Breakdown products of explosives can in themselves be toxic or in certain cases present an explosive risk. Table B.6 in Appendix B provides details of the breakdown products of the more common explosives. Both the individual breakdown products and the combination of materials from the breakdown of a range of organic and inorganic explosives can lead to the formation of highly sensitive compounds. Examples are the conversion of picric acid to picrate salts, ammonium perchlorate into metal perchlorates such as copper and the conversion of lead azide into copper azide.

The decomposition rate of explosives varies and is dependent upon the following:

- the soil or storage conditions around the explosives; and
- the properties of the explosives themselves.

Soil conditions can have a marked impact on the rate of decomposition and on the materials which may be formed. The most important parameters affecting the decomposition of explosives are:

- moisture content – e.g. unstable metal salt explosives decompose in contact with water. However lead azide in contact with copper and water can, over time, form highly sensitive copper azide;

- pH of soil – certain organic explosives can decompose in acidic soils by a process known as acid catalysed decomposition. Metal salt explosives such as lead azide will decompose in the presence of acidic soils;

- soil type and humus content – organic explosives can be adsorbed onto humus materials and can, under favourable conditions, biodegrade. Also vegetation can absorb organic explosives;

- temperature – may assist biodegradation;

- concentration of the explosive in soil – low concentrations of organic explosives are more likely to be biodegraded or absorbed by plant root systems. High concentrations can inhibit microbial action;

- physical form – e.g. powdered TNT is more likely to biodegrade in soil than block or flake TNT.

Most explosives are very persistent in the soil, especially when present in high concentrations. Characteristics of breakdown products of commonly found explosives are described in Table B.6 presented in Appendix B. The natural breakdown of explosives in soil is poorly understood and further research is required.

In addition to explosives contamination, conventional contamination from items such as buried shells can also occur on explosives manufacturing and processing sites. For example metals contamination may occur from the corrosion of shell casings, paints, pyrotechnic or initiator compounds.

3.5 Toxicological and Physico-chemical Data

Certain chemical specific physico-chemical parameters can provide valuable information relating to the behaviour of these compounds in soils. Important parameters considered in the CLEA model include:

- solubility in water;
- Henry's Law Constant
- vapour pressure;
- octanol water partition coefficient;
- Organic Carbon partition coefficient;
- Diffusivity in Air;
- Diffusivity in water.

In most cases the required toxicological and physico-chemical data for these substances are incomplete or the data are not fully verifiable.

3.6 Mobility of Main Explosive Contaminants

As explosives cover a wide range of compounds, their mobility within the soil and groundwater environment is variable. The mobility of the main groups of explosive compounds is summarised in the following sections.

3.6.1 Organic explosive compounds

Explosive	Solubility in water	Physical mobility
TNT	Low. However certain by-products such as 'red waters' are highly soluble	Low. However has been found to collect in high concentrations close to or under process buildings.
RDX	Low	Low. However may be transported as a suspension in water or dissolved in a solvent such as cyclohexanol.
HMX	Low	Low. However may be transported as a suspension in water or dissolved in a solvent.
PETN	Low	Low. However may be transported as a suspension in water or dissolved in a solvent.
Picric acid	High	A solid, but can be leached from soil can react with metal salts (e.g. salt water) to form insoluble picrate salts.
Tetryl	Low. However can degrade to picric acid.	Often occurs in powder form and thus could be carried in a water suspension.
NC	Insoluble	Often occurs in very fine fibrous form and thus can be carried in a water suspension.
NG	Low	A liquid above 14°C - a DNAPL.
EGDN	Medium	A liquid above -20°C - a DNAPL.
Picrite	Low (at ambient temperatures)	Often occurs in powder form and thus could be carried in a water suspension.
HNS	Low	Low. However may be transported as a suspension in water or dissolved in a solvent.

3.6.2 Metal salt explosives

Metal salt explosives are insoluble in water. However as most are in fine powder form, the explosive or its degradation product could be carried in suspension in water.

3.6.3 Pyrotechnics

As these compounds are generally simple powder mixtures, their mobility will be dependent on the mobility of the ingredients (see Table B.5 in Appendix B).

3.6.4 Chlorate and perchlorate based explosives

Solubility in water of the raw material chlorates and perchlorates is dependent on the anion. Thus all ammonium, sodium and potassium compounds compounds are relatively soluble, whilst most heavy metal salts are insoluble. When incorporated into explosive mixtures, the soluble chlorates and perchlorates become bound to the explosive material. However, dependent on the specific explosive composition, the chlorate or perchlorate compounds may be leachable over time if they are in contact with water or wet soil.

3.6.5 Ammonium nitrate based explosives

Ammonium nitrate is highly soluble in water. Thus any explosive mixtures such as amatol can be expected to leach ammonium nitrate if in contact with water or wet soil. However, some gels and emulsions can be very water resistant.

4. SITE CHARACTERISATION

KEY QUESTIONS ANSWERED IN THIS SECTION

1. Which additional information sources should be used for a desk study?
2. What are the main differences from a conventional contaminated land investigation?
3. Are special sampling and sample handling procedures required?
4. What should be analysed for and when?

4.1 Scope

This section provides information on the specific approach that should be followed when conducting desk studies and site investigations on land potentially contaminated with explosives. The overall approach to characterisation of such sites is, in the main, similar to that for conventional sites. Any such generic guidance is excluded from the scope of this section which relates solely to the particular issues associated with explosives contaminated land.

4.2 Desk Study

4.2.1 Key issues

The following issues are of particular importance in relation to the desk study phase, when considering sites where explosives may be encountered:

- lack of information (in particular in relation to sites involved with military explosives) may be a major barrier to understanding the activities carried out and the contaminants which may be encountered;

- a lack of information does not mean that explosives are not present. Enquiries to MoD often result in a response that they do not have any records of explosives or explosives devices being processed on a site. Reliable corroborative negative or positive evidence should be sought if possible. Further details are given in Environment Agency R&D P5-042/TR/01 in this series;

- historical “free from explosives” certificates should be treated with care as often the inspections only involved visual checks for surface contamination;

- knowing where to look for the relevant information, and how to interpret the information which is available, are important considerations. Also, as with other MoD sites, this will often mean that specialist assistance must be sought from independent organisations familiar with explosives manufacturing and processing sites;

- it is unlikely that MoD departments would be able to effectively answer issues on explosive manufacturing or processing;

- due to the possible acute hazard from explosives contamination of explosives buildings, the desk study needs to address building history and use.

4.2.2 Group numbers

As with other military sites group numbers were used to indicate particular functions or activities. Records or plans (if available) may indicate a particular group number relating to explosives manufacture. Care is needed with interpreting this information and it is important not to confuse these groups with group numbers associated with squadrons – for example airforce squadrons which have their own system.

The production, processing and storage of explosives and explosive devices is segregated into defined groups. Both historical and current explosive establishments use or used a numbering system to identify the explosive group. These numbers did not usually vary and as such a particular group number, if indicated on plans, would indicate the presence of a particular operation and a specific product.

Group No.	Description	Common Operation
1	Initiators:	Production of caps, detonators, fuses, primers and tracer fillings.
2	Fuse Magazines:	Storage of exploder pellets, exploder bags, powdered TNT and tetryl.
3	Fuse Filling:	Fuse pressing and pressing, percussion fuses, detonator filling.
4	Gunpowder/ Secret:	Blending and pressing of black powder and time fuses. This group was also generally used for Secret work on research and development projects for all aspects of defence.
5	Cartridges:	Filling of propellant charges, cartridges and rocket assembly.
6	Pyrotechnics:	Smoke, flare producing compositions, tracer fillings.
7	Small Arms:	Filling of small arms normally subdivided by type.
8	HE Filling:	High explosive mixing and filling of bombs, shells and grenades.
9	Filled Storage Magazines:	For storage of finished devices.
10	Infrastructure:	General engineering, heat & power generation, administration etc.

There are a number of important points which should be taken into account with regard to group numbers:

- although group numbers are important for determining the range of activities which may have been carried out on a particular site, there was often a good deal of movement of activity around any one site throughout its history of operation. Some sites operated for 100 years or more;

- the presence of a group number should therefore be used as a pointer to alert those investigating the site as to the presence of the associated contaminants but should not be taken to mean that those contaminants will only be found in the area indicated on available plans;

- if evidence is not supportive to the contrary, then it should be assumed that a group may have at some point been located elsewhere on site than its last known position. Some older sites predate the group numbering system;

- Group 8 – filling of main charge. This group could have included Chemical Weapons (CW) agents if chemical weapons were being filled on the site. In general this would have been mustard, phosgene or tear gases;

- explosive manufacturing facilities did not use this system neither did WWI facilities.

4.2.3 Security classification

Some information (concerning military explosives sites) may still be classified as restricted or secret due to its sensitivity. In many cases the information may be made available for viewing or declassified at request after review. Where viewing or declassification is not possible, specific questions on environmental issues can be asked and information provided where it is considered that such information is in the "public interest".

4.2.4 Operational time periods

The period of site operation is an important factor in determining which explosives may be present. Table B.2 in Appendix B gives details of the initial dates of the use of some common explosive substances in the UK.

4.2.5 Common mistakes

- pseudonyms may have been used for documents, plans and other information for a site. For example, the Elstow Ordnance depot in Bedfordshire is listed as the Blackpool Hotel;

- operational army units may have a code regiment number. For example, a maintenance regiment may actually be identified as an explosives disposal unit;

- manufacturing terminology used may be confusing or innocuous such as:

  - cap;

  - motor;

  - starter;

  - primer;

  - booster;
  - sieving;
  - drying;
  - stoving;
  - incorporation;
  - steeping;
  - mixing;
  - rolling;
  - pressing;
  - doping.

- explosive processes always require certain infrastructure. These may not be readily identified by documentary evidence but they should still be assumed to be present. For example, explosive disposal areas, burning grounds;

- if only one explosive process is detailed, then it is often incorrectly assumed that there is only one explosive to consider. Changing site history, site processes, explosive mixtures and the degradation of explosives, can give rise to a range of other explosives being present;

- assuming that non explosive process areas are free from explosive contamination is a common mistake. Exigencies of wartime operations meant that often rules for danger areas were relaxed and explosives may have been transported, stored or processed outside of the areas designated for explosives;

- unfamiliarity with explosive manufacturing may lead to misinterpretation of structures and site layouts. A trained specialist can often establish a site use and individual building use from its structure and general site layout. Commonly, buildings are wrongly interpreted as being explosive process or storage buildings when in fact they may have been used for more conventional uses, or vice-versa. This indicates the need for some peer review or input during the desk based review by a specialist consultant with appropriate training, experience, and knowledge.

4.2.6 Desk study check-list for explosive sites

This check-list is intended to supplement the check-lists for a Phase 1a Risk Assessment contained in the Model Procedures (in preparation) and DoE (1994).

Specialist information sources

- MoD – Historical Army Section
- MoD – Defence Estates/Defence lands
- MoD – Library Whitehall
- MoD – Safety Services
- MoD – Land Quality Assessment (LQA) groups
- Home Office – Emergency Planning Office
- Public Record Office
- HM Inspectorate of Explosives
- Local Libraries and Historical Archives
- Explosives manufacturing companies– Historical Archives
- Specialist Consultant

Establish the operational period of the site

Establish whether any of the following features were present on the site:

- Bulk Chemical Storage
- Chemical Plant
- Filling & Assembly
- Magazines
- Laboratories
- Railway Network
- Water features (e.g. ponds or canals)
- Disposal Sites
- Burning Grounds
- Firing Ranges
- On site heat & power stations and electrical substations
- Engineering Workshops
- Laundries

These specialist information sources do not offer a commercial information service like local authorities or statutory bodies. Enquiries can be difficult and can take in excess of three weeks to reply. Many of the information sources may require a personal visit.

4.3 Site Inspection and Investigation

4.3.1 Site inspection

The site inspection visits should always be based on the maximum available information which can possibly be obtained from the desk study phase. The site inspection may be conducted in two parts where a return visit is conducted if the initial visit identifies areas that require further documentary research.

Phased visits can be particularly important for possible explosive contaminated sites to ensure due consideration is given to acute hazards which may be present.

Site inspection staff will need to be equipped with the relevant level of PPE and should have appropriate training and experience (see Section 7 for health and safety aspects).

At operational sites, access may be restricted due to site safety or security procedures and site specific procedures may need to be followed when carrying out inspection or intrusive works.

Site inspections should only be conducted under the supervision of a person trained and experienced in Explosive Safety Management, Health & Safety, ammunition recognition (where appropriate) and the ability to identify buildings, processes, materials associated with explosive operations.

4.3.2 Site investigation

The DETR (1997) and DoE (1994) documents describe the generic aspects of site investigations. The following section and information boxes outline specific issues of site investigation in relation to explosive sites.

Approach to Site Investigations

When investigating the risk from explosives or explosive devices, it is essential that a clear methodology based on safety risk assessment is adopted irrespective of external influences such as time constraints. All works, depending on the anticipated risk, should be either supervised or conducted by a person trained and qualified with suitable experience in explosive safety management (ESM). More specific health and safety issues are discussed in Section 7.

Investigation Design

The design of the investigation will be similar to that conducted for conventional sites except that explosives sites require certain restrictions on methods of intrusive investigation.

The distribution of exploratory points may differ for an explosives site. For conventional sites, those areas shown to be more remote or apparently unused would perhaps be investigated to a lesser degree than an area of obvious industrial activity. Due to the hazards of explosives, processes such as disposal, or testing may have been conducted in remote areas of the site away from the main manufacturing area. Little visible evidence may be available of historical activities due to demolition, covering with earth or simply vegetation grow back. Some of these 'remote' activities may not have been fully documented. Consequently such remote areas may in fact carry a higher risk of explosive contamination and consideration should be given to allocating a higher than normal level of priority. Given the unusual distribution of contamination which may be found on explosives sites, the use of grid patterns and geostatistical methods for locating exploratory holes is less likely to be effective in locating ‘hotspots’ than on many conventional contaminated sites.

Alternatively appropriate geophysical techniques may be considered to scan certain areas of the site for evidence of buried structures, metal objects or disturbed soils.

Box 4.1 Scenario - Preparation for site investigation

Several hundred acres of a Royal Ordnance Factory were unused by the current factory complex. The area consisted of mature trees and bushes and was poorly drained. The current factory (designed and built during WW II) had not utilised this area. The thick undergrowth and mature trees gave the appearance of being natural ground.

Strong anecdotal evidence told of this area being the site of a WW I ammunition filling factory, but no records of this remained in the operating factory. Public record research unearthed a wealth of evidence including plans of the WW I factory. Using these plans, it was possible to locate foundations of the buildings buried under vegetation and peat. The information enabled an appropriate site investigation to be designed.

Box 4.2 Scenario - Unexpected Site Investigation Findings

A site investigation of an ordnance depot revealed explosives contamination in a field thought to be outside of the danger area. It was found that contaminated ash from the burning ground had been spread across the surrounding land.

Buildings that have been used for the manufacture or processing of explosives are likely to contain residues of explosives and represent a significant potential explosives hazard. Process buildings on operational or derelict sites should only be inspected and assessed by a competent person trained in the potential hazards that may be present.

Box 4.3 Scenario - Inadequate Investigation Design

During WWII an explosives factory had been under such pressure to produce propellant that a propellant press had been installed without the safety asphalt floor being laid. A temporary linoleum floor had been installed instead, which was subsequently never replaced.

When the press was to be removed in 1948 it seemed inconceivable that any of the propellant could have become trapped under the bedding plate, which was sealed to the floor. Oxy–actylene torches were used to cut through the securing bolts. Almost immediately jets of flame shot from under the press. The fire quickly became very violent and engulfed the building. Fortunately no one was seriously injured in the accident.

Subsequent investigation showed that the plant had been operated for some time before being sealed and substantial quantities of explosive had accumulated under the bedding plate and in the cracks of the linoleum floor.

This incident demonstrates the error of assuming a location to be free from explosives just because it is difficult to see how it could be otherwise.

Investigation Techniques

Table 4.1 summarises applicability of investigation techniques to the principal potential pollutant sources.

Note - when dealing with explosives, it is essential that a disciplined attitude and safety regime is adopted irrespective of external influences such as time constraints. Precautions should always be taken in line with the above guidance.

Prior to any investigation a full safety briefing must be given to all site operatives. Depending on the anticipated risk, the works can either be conducted by contractors under direct supervision of a specialist or by a specialist contractor. Under no circumstances should the work be attempted by persons who do not have appropriate training, experience or insurance to conduct such work. Further details on different techniques are given below:

- **non-intrusive techniques** - a range of non-intrusive geophysical techniques are available that can help identify areas of waste disposal, disturbed ground, pollution plumes and other relevant features. Specialist geophysical techniques are increasingly being used for buried ordnance detection. Current development of downhole geophysical techniques will allow boreholes to be advanced with geophysical instruments held within the leading edge of the drill enabling buried ordnance to be detected in advance of the drilling process. Interpretation of geophysical data is an important factor and should be undertaken by experienced operators who know how to calibrate their equipment for munitions testing. Typical methods used will include electromagnetic profiling, magnetic profiling and ground penetrating radar;

Table 4.1 – Applicability of investigation techniques to principal potential pollutant sources

PRINCIPAL POTENTIAL POLLUTANT SOURCE Harm	MAIN INVESTIGATION TECHNIQUES (See Key Below)	APPLICABILITY/CONSTRAINTS
Explosives contaminated shallow soils	1,2,3	Under no circumstances should probe holes or boreholes be conducted unless open excavation has proven the base of potentially contaminated soils/made ground. In some scenarios, remote probing may be the only investigation option. Works to be conducted with extreme care to a written protocol under the supervision of an experienced person trained in explosives safety management.
Explosives contaminated building fabric	6,7	Core sampling should normally be conducted remotely.
Explosives contaminated underground utilities (e.g. drains, sumps and soakaways) or deep soils	1,3,4,5, 6	Works to be designed and conducted with extreme care to a written protocol under the supervision of an experienced person trained in explosives safety management.
Explosives threat to controlled waters	1,4,5	Works to be designed and conducted with extreme care to a written protocol under the supervision of an experienced person trained in explosives safety management.
Buried munitions	1,2,3,5	Probe holes or boreholes should be employed in conjunction with downhole geophysics techniques. Such work should only be conducted by a specialist.
Asbestos release	1,2,3,4,5	As per conventional sites, although bulk asbestos may be present in large quantities in discrete locations as well as finely dispersed in soil close to where asbestos produces were used. Dust suppression is a major consideration.

KEY:

1. Non intrusive Geophysical techniques
2. Hand excavated trial pits
3. Mechanical excavated trial pits
4. Probe holes
5. Boreholes
6. Surface swabs
7. Core sampling

- **intrusive techniques** - such work needs to be supported by a safety risk assessment conducted by competent persons. Remote intrusive investigation should be considered where the risk to operatives is considered unacceptable. Remote work may involve excavation, building fabric coring or drilling by machines which are operated by control cables at a safe distance from the work area. Hand or machine excavated trial pits are the preferred methods for investigating potentially explosively contaminated soils. These methods expose a large volume of soil which allows for representative viewing and sampling of the strata. If excavated soil is particularly dry, consideration should be given to wetting the excavation area as water generally desensitises explosives. Any obstructions or features that require further investigation can often be seen and excavated around if required. Boring and probing methods are to be avoided until either characterisation of the soils by other methods has proved a low explosive contaminant risk or the probe or borehole can be progressed through an open excavation into "clean" underlying soils. Boreholes or probeholes are often not advisable because of the risk of striking an explosive device or a pocket of highly concentrated explosive contamination. Even when "clean" natural soils have been proven, particular care is still required when mobile DNAPL explosives such as nitroglycerine are suspected of being present. Chiselling is to be avoided where possible;

- **surface swabs and core sampling** - clean cotton wool soaked in a suitable solvent (e.g. acetone) is appropriate for surface swabbing of building fabric surfaces. Unless the risk assessment demonstrates acceptable risk, building core samples should be taken using a remotely operated coring machine. Persons with specialist knowledge of the explosive manufacturing processes employed should be involved in the selection of areas for swab or core sampling.

Sampling

Actual samples should be taken in general accordance with good practice for conventional sampling paying particular attention to the following:

- samples should be taken using non-sparking implements only;

- samples should be placed in amber glass jars with PTFE (teflon) liners and using a sealing lid suitable for use with primary explosives;

- samples suspected of or to be tested for explosives contamination should be tested prior to transport on the public roads, unless special exemption has been granted by HM Inspectorate of Explosives. Samples which are suspected or proved to contain >1% by weight of explosives may require a licence for storage and transportation. All sample packaging of such soil samples should comply with the Packaging of Explosives for Carriage Regulations 1991, and the Classification and Labelling of Explosives Regulations 1983;

- to overcome the administrative difficulty of transporting suspect explosives contaminated samples, on-site screening by appropriate methods can be used to demonstrate that the samples do not present an explosive risk during transportation.

Chemical Analysis

There is a wide range of contaminants that may be encountered on explosives manufacturing sites within soil, building fabrics, surface and ground waters. Industry Profile, DoE (1995a), can be used to assist in the choice of contaminant suite. Details of suites relating specifically to explosives are provided below.

The following points are specific to the analysis of explosives in solid and liquid samples:

- on-site explosives screening using appropriate equipment and methods can be cost effective and improve safety of sample handling. It can be used to detect or map higher level contamination using semi-quantitative methods and has the benefit of fast sample turnaround. Proprietary test kits should only be used if these have been proven on the soil and contaminant mix found on the site and found to meet the screening objective. Many test kits are compound specific and therefore may not be appropriate for screening for the range of explosives suspected;

- given the specialist nature of explosives analysis, all samples should only be analysed by a competent laboratory using proven techniques. It may be necessary for the laboratory to hold an explosive licence;

- if separate laboratories are proposed for explosives and conventional testing, then the laboratory conducting the explosives analysis must advise the conventional laboratory on safe testing methods based on any identified explosive content. Appropriate time should be allowed for this liaison between laboratories, before the investigation is carried out.

Specification of Chemical Analysis

- **organic explosive compounds** - there are no standard published methods for explosives analysis of soil or water samples. The laboratory conducting such analysis needs to have developed such methods and hold appropriate accreditation for analysis of explosives. Unless the desk study clearly indicates that only very few explosives compounds were present on site, it is recommended that analysis for the 11 explosives compounds listed in Section 3.2.1 forms the basis of the explosives suite. It may be necessary to extend this suite if other explosives are suspected of being present or there is a requirement to analyse for possible breakdown products (see section 3.4 and table B.6);

- **metal salt explosives** - section 3.2.2 lists a range of the more common inorganic explosives that may be found on explosives sites. This list is by no means exhaustive and there is a wide range of heavy metal compounds that have been used as explosives in the past. In most cases the original metal salt explosive will have decomposed, thus metals analyses can be used to detect the main decomposition product risk. If it is suspected that the metal salt explosives are still present (e.g. within a building structure) then specialist advice must be sought as safety in such cases is paramount;

- **pyrotechnics** - as these materials can be composed of a variety of compounds (see Appendix B.5 for examples), specialist analytical methods may be necessary. Surrogate testing (e.g. for metals) may be appropriate;

- **chlorate, perchlorate and ammonium nitrate based explosives** - where the target explosives are known to be simple mixtures, or decomposition products are being targeted, it is appropriate to analyse for individual ingredients (e.g. Amatol – analyse for TNT and ammonium nitrate). Specialist analytical support is required where it is considered necessary to analyse for composite or plastic propellants;

- **other contaminants** - extensive use of asbestos based materials on such sites necessitates that soil samples are analysed for asbestos type and quantity as required. Other conventional contaminants suspected of being present can be analysed for using industry standard methods after the sample has been shown not to be contaminated by explosives.

Detection Limits

The choice of detection limits for analysis is wholly dependent on the intended use of the site. As part of the desk based review and subsequent risk assessment, the contaminant pathway receptor pollutant linkages can be established. From the identified pollutant linkages, site specific requirements can be used to establish what concentrations of explosives in soil, surface or groundwater are acceptable for the proposed use. From this determination, achievable detection limits can be specified to the laboratory.

5. SITE EVALUATION

KEY QUESTIONS ANSWERED IN THIS SECTION

1. What are the probable pollutant linkages that should be assessed?
2. Which of these pollutant linkages are likely to be the most significant?
3. Are there appropriate 'trigger/guideline' values that can be used to benchmark the investigation data?
4. When is it appropriate/inappropriate to apply conventional risk assessment methods to this category of special sites?

5.1 Scope

This section is intended to supplement the relevant Model Procedures (DETR, in preparation) and associated guidance on risk estimation and risk evaluation. It describes important aspects that should be considered when evaluating explosives sites and identifies sources of relevant background information and data.

5.2 Pollutant Linkages

5.2.1 Principal issues

Any risk assessment should be conducted in line with the Model Procedures (DETR, in preparation). The special considerations noted in this section should also be addressed.

5.2.2 Acute risks from contaminated soil or buildings

The principal pollutant linkages are as set out below.

Source	Pathway	Receptor
Shallow soils with high localised concentrations of explosives.	Explosion or deflagration.	1. Site workers – in particular persons required to excavate soil. 2. In extreme cases, persons on neighbouring land.
Explosives contaminated deep soils or underground utilities.	Explosion or deflagration.	Maintenance workers where soil or utilities are being excavated.
Buried Munitions.	Explosion or deflagration.	Site workers - in particular persons required to excavate soil.
Explosives within buildings or plant and equipment.	Explosion or deflagration.	1. Site users. 2. In extreme cases, persons on neighbouring land.

Although the chances of acute risk from explosives in soil and buildings are normally low, the effects can be traumatic. Explosive incidents generally result directly from human actions or inactions. To assess explosion risks more accurately, it is appropriate to use a risk assessment process which meets the requirements of The Health & Safety at Work Regulations 1992.

Human health risks from explosives sites are likely to be dominated by the perceived or actual physical risks of explosion. Accidents (e.g. explosions) can occur in unexpected circumstances as Box 5.1 illustrates.

Box 5.1 Scenario - Non-obvious Acute Risks

An experienced explosives worker was using an oxy-acetylene torch to cut through some steel pipework thought to be free from explosives. Approximately 250 grams of explosives remained in the pipe and the ensuing explosion shattered all of the workers limbs and caused significant burns. The worker died some 2 hours later.

This example illustrates the difficulty in advising what quantity or concentration of explosives can constitute a risk to human health. An expert in explosives risks or the HSE Explosives Inspectorate should be consulted in all cases where acute risks are being evaluated.

Possible additive or synergistic effects should also be considered and COSHH assessment should be conducted for any anticipated explosive compounds. Box 5.2 provides an example of an additive/synergistic effect.

Box 5.2 Example – Possible Additive or Synergistic Effects

Picric acid will react with metals, corroding them and forming impact sensitive salts (picrates). These picrates are very sensitive explosive compounds which are far more hazardous than the picric acid which formed them.

Changes in soil and other conditions, such as lack of moisture and increasing temperature, can affect the risk of explosion. This is illustrated in the following examples in Box 5.3.

Box 5.3 How Changing Conditions can Affect the Stability of Explosives

Example 1

Cordite (an NC/NG based gun propellant) contains a stabilising mineral jelly to counteract the breakdown of the two explosive constituents. As the stabiliser chemically depletes, the breakdown of the NC and NG occurs, especially when stored in dry warm conditions. This chemical breakdown can accelerate to the point where heat builds up. If this heat is not dissipated spontaneous combustion can result. Storage of bulk cordite over decades has been known to result in a deflagration and destruction of buildings.

Example 2

When NG freezes its comparatively 'stable' liquid form becomes a very shock sensitive crystalline form. Even the thawing action of frozen NG can result in an explosion due to the NG crystals rubbing against each other.

In assessing risks, it may be important to consider all the likely current and future receptors (e.g. workers involved in decommissioning and redevelopment of an explosives site and future users – residential, open space and commercial/industrial).

The results of core and swab samples can be used to assess the hazard posed by residual explosives within building fabric. The key to evaluating risk in this context, is knowledge of current and future use. Non-explosive related re-use requires assessment of risk (acute and chronic) from contamination found in swab samples. In addition where core samples show there is a risk from explosives within the building fabric, the risk assessment needs to consider whether employment of controls on building maintenance work (e.g. precautions controlling drilling into or disturbance of the building fabric) can reduce risk to acceptable levels.

5.2.3 Chronic risk

Human Health

This section concentrates on explosive chemicals. However, risks from raw materials and associated chemicals should also be included in any site evaluation.

Many explosives can exhibit toxic properties. Provided that there is satisfactory evidence that the concentrations are below the levels which could present a risk of explosion or fire, then the explosive can be treated as a conventional contaminant.

The principal pollutant linkages in respect to the toxicity of explosive chemicals are as set out below.

Source	**Pathway**	**Receptor**
Shallow soils with concentrations offering a toxicological hazard.	Ingestion Inhalation Dermal	Site users – in particular persons required to excavate soil.
Explosives contaminated deep soils or underground utilities.	Ingestion Inhalation Dermal	Maintenance workers where soil or utilities are being excavated.
Explosives within buildings or plant and equipment.	Ingestion Inhalation Dermal	Site users and maintenance workers.

Ingestion is probably the main pathway although some explosives such as NG have a significant vapour pressure. NG has been known to become absorbed into wood and can be re-released into the atmosphere on heating. Some explosives e.g. nitro-aromatics such as TNT and tetryl can be absorbed through the skin. Reference should be made to toxicological and physico-chemical data of the specific explosives being considered in the site evaluation.

UK Guideline Values for the protection of human health for explosives do not currently exist.

An Environment Agency research project on toxicological data and guideline values for Explosive Substances' is in preparation, and provides physico-chemical and toxicological data for eleven explosive substances. The eleven substances included in the study are essentially the same as the list given in section 3.2.1 with the exception that it includes 2,4-dinitrotoluene or 2,6-dinitrotoluene rather than nitroglycol (EGDN). The output of this project will include:

- physico-chemical data for the eleven explosive substances;
- a series of toxicological reports (one for each explosive substance);
- the toxicological data will be used to derive Guideline Values for explosives contaminants in soils for the protection of human health derived using the CLEA model.

For the more unusual metals and raw materials or inorganic and organic explosives, toxicological data are available from the open literature. Relevant sources include the World Health Organisation (WHO) and the United States Environmental Protection Agency (US EPA) IRIS database.

For the breakdown products of explosives less information may be available and very focussed research may be needed. Refer to Section 3.4 and table B.6 for information regarding breakdown products.

Water Environment

The principal pollutant linkages are as set out below.

Source	Pathway	Receptor
Shallow soils with concentrations of mobile explosives.	Leaching or in suspension by water. In solvent solution.	1. Surface waters and perched groundwater. 2. Groundwater
Mobile explosives contaminated deep soils or underground utilities.	Leaching or in suspension by water. In solvent solution.	Groundwater including perched groundwater.
Liquid explosives (e.g. nitroglycols such as NG).	Percolation through soils. In solvent solution.	Groundwater

Reference should be made to Section 3.6 for some initial guidance on the mobility of explosives and to toxicological and physico-chemical data of the specific explosives being considered in the site evaluation.

Risks to the water environment are likely to be important in driving decision-making as certain explosives are soluble or may be transported in suspension (see Section 3.6) and therefore subject to the same migration potential as many other contaminants.

- NG and the related nitrogycerols being liquids with densities greater than that of water are known to behave as dense non-aqueous phase liquids (DNAPLs);
- picric acid is relatively soluble in water. Picric acid is also a possible degradation product of Tetryl. Other soluble explosive materials are ammonium nitrate and ammonium perchlorate;
- explosives suspended in water can migrate, especially into surface water courses or fissured strata. Examples are NC, Picrite, PETN and various other explosives if processed into fine powders;
- organic explosives are all soluble in certain organic solvents. Such solvents are used in recrystallisation processes. If these solvents were or are present, (e.g. leaking from storage tanks) explosives can migrate with them;
- effluent, liquid and slurry wastes can drain into controlled surface waters flowing through or adjacent to the site e.g. ‘red waters’ from TNT production.

It was common for many explosive manufacturing processes to produce liquid wastes and effluent – both explosive and non-explosive related. Historically it was common practice to deal with this form of waste by a series of interlinked settling ponds to remove suspended explosives. Invariably these settling ponds drained into the local surface water system.

Effluent treatment technology including, for example, acid neutralisation and reed beds is now employed. Historically, effluent may have been released into surface water drainage, soakaways or commonly effluents such as TNT “red waters” were pumped via extensive pipelines to discharge into local rivers or off shore.

It is appropriate to use conventional risk assessment models and frameworks to assess the risk of such explosives to the water environment.

Ecological Systems

Pollutant linkages relating to harm to flora and fauna could be an issue at explosives sites as these installations are often located in open, remote and frequently semi-natural, rather than agricultural, areas. Also, the large size of many explosive sites raises the possibility that several different habitat types could fall within the boundaries of the land. Key considerations include:

- the potential for explosives sites to be located near to, or even included within their boundaries sensitive ecological sites such as SSSIs (Sites of Special Scientific Interest);
- given the remoteness and sparse layout of explosives sites, it is common to have a variety of wildlife habitats on a site. Common fauna found on explosives sites (including operational sites) can include badgers, deer, rabbits, newts, bats, birds of prey, foxes and grass snakes;
- release of bioaccumulative agents, especially where this occurs directly into surface waters.

Principal pollutant linkages are:

Source	Pathway	Receptor
Shallow soils with concentrations offering an ecotoxicological hazard.	1. Bioaccumulation 2. Surface water or perched groundwater. 3. Ingestion	1. Plants growing on contaminated soil. 2. Plants in neighbouring land. 3. Fauna

There is a dearth of ecotoxicological information on explosive substances. A number of explosives such as TNT and NG are known to be toxic to fish within streams and rivers. Evaluation of risk needs to be compatible with the definition of significant harm as described in the Contaminated Land (England) Regulations 2000 and the accompanying DETR circular.

Although rare flora and fauna are often found on explosives manufacturing sites, some within on-site SSSIs, evidence shows that on balance explosives sites do not seem to pose a significant risk to these ecological systems. However, each case should be considered individually. The main threat to the ecology from explosives sites comes from water pollution and effluent – see section on the water environment. It is possible that plants absorb explosives by uptake from the soil and research is necessary for this phenomenon to be understood. However, uptake by plants is not necessarily a problem unless the plants serve as a pathway to a receptor (such as consumption by humans) or the explosive substances prove to be toxic to the plants.

Buildings

Certain explosives or explosives reagents are also corrosive to some building materials. Examples include:

- acidic reagents and residual sulphates in soil from sulphuric acid neutralisation;
- salts such as certain metal salts, chlorates and perchlorates in contact with steel structures and under damp conditions can accelerate corrosion;
- certain organic explosives and reagents have the potential to migrate through plastic pipes.

5.2.4 Special considerations for explosives sites

In developing the risk assessment, consideration should also be given to the following issues:

- As the historical information collected during the desk study may be incomplete, and given the real potential for acute risks, should the risk assessment be appropriately qualified?
- Explosive contamination sources can often be small in area (e.g. at entrances and exits to buildings, or small areas of on-site waste disposal). Given that the site investigation design should have some statistical basis, what are the chances and the potential effect of an explosives related 'hot spot' being missed by the sampling regime? Any remediation strategy should address this question in terms of:
    - the threat posed by such a 'hot spot' to the future use of the site;
    - the possibility that any planned development work on the site will unknowingly spread this contaminated 'hot spot' across the site.

5.3 Site Evaluation Check-list

Have the specific uncertainties associated with explosives sites been considered?
Have non-intrusive investigation methods been considered?
Is there an explosion risk and if so has this been evaluated?
Is there a toxicological risk and if so has this been evaluated against appropriate guideline values?
Is the consultant/contractor conversant in relevant legislation relating to explosives (see Section 7)?
Does the consultant/contractor have insurances that specifically state working with explosives?
Does the consultant/contractor need to have appropriate licences to work with explosives?
Does the consultant/contractor have ‘competent’ persons to deal with explosives?
Has the Health & Safety Executive – Explosives Inspectorate been informed of the potential site works?
Has a Risk Assessment been conducted that specifically addresses anticipated risks from explosives?
Have the relevant authorities been informed, for example Police, Joint Services Explosive Ordnance Disposal and Emergency Planning departments as required?
Is on-site screening/analysis required?
Are there any other receptor groups at risk and if so have they been evaluated?
Is a specialist laboratory being used?
Does the receiving laboratory need to be licensed to store and analyse for explosives?

6. REMEDIATION ASPECTS

KEY QUESTIONS ANSWERED IN THIS SECTION

1. Which remediation technologies could be appropriate?
2. What are the main constraints and advantages to each of the applicable remediation technologies/engineering methods?
3. What are the anticipated perception/community impacts of the remediation technologies?
4. Are the technologies compatible with site reuse?
5. How can the remediation process be validated?

6.1 Scope

This section provides detail on the most applicable remediation technologies which are currently available (or are likely to be available in the near future) on a commercial scale within the UK. The intention of this section is to enable the reader to understand in general which remediation technologies may be appropriate to remediate explosives contaminated soil or groundwater. This section does not provide detailed guidance on remediation design, but is intended to highlight the key issues which will need to be considered in the remediation design.

Although under certain conditions some explosives or their degradation products can contaminate groundwater, the most significant media for such contamination are soil, buildings and associated utilities. Consequently the main emphasis within this section is on soil and building remediation.

6.2 Social Concerns and Perceptions

Explosives contamination has the potential to increase the public's negative perceptions of contaminated land. This concern is often driven by a lack of knowledge and understanding of the facts, which can be compounded in the case of military explosives sites by the secrecy which often surrounded them. However, the public have a desire to know that these issues are being managed sensibly and professionally. Reference to 'Communicating Understanding of Contaminated Land Risk' (SNIFFER 1999) may be of assistance.

When an explosives manufacturing site is being remediated for redevelopment it is important to address these social concerns and perceptions, by a mix of technical and managerial actions such as:

- a risk communication strategy may need to be developed. Decisions about contaminated land are not made on a purely technical basis. Risk communication needs to address risk management issues in order to gain public and stakeholder confidence;

- it may be necessary to demonstrate the successful remediation of other similar sites;

- the standard of remediation criteria may have to take some account of public concerns – especially where residential development is contemplated.

6.3 Principal Remediation Technologies

The following sections provide general information to assist with the selection of an appropriate remedial approach for explosives manufacturing sites. The technologies that are available for remediation of soil and groundwater contamination can be grouped into the following categories:

- Civil Engineering Approaches;
- Biological Based Technologies;
- Chemical Based Technologies;
- Physical Based Technologies;
- Solidification and Stabilisation Based Technologies;
- Thermal Based Technologies.

6.3.1 Civil engineering approaches

Cover systems, barriers, licensed landfill

Containing or covering explosives contamination is only an option if the concentrations in soil are well below the concentration likely to sustain an explosive event or underground fire. However it can be a viable option as long as the residual risk can be appropriately managed (e.g. where the capped contamination is part of a managed open space, where deep excavation can be controlled and where the quantity of explosive material involved is relatively small).

A cover/barrier solution is not normally considered appropriate for surplus or buried explosives devices or munitions. If such devices are present on a site planned for remediation or redevelopment, such devices should be recovered and destroyed. However it may be appropriate to use a cover/barrier solution for soil in which there is a small but acceptable risk of explosive devices remaining and where identification and removal cannot be justified.

Disposal to licensed landfill of explosives contaminated soil has occasionally been permitted where:

- the explosives concentration is demonstrably < 1%.

- there are no visible discrete explosives present (e.g. lumps of TNT or cordite grains).

- the explosives contaminated soil forms a small proportion of the landfill contents.

It should be noted that work on explosive wastes is normally excluded from waste management licensing.

Disposal to licensed landfill is a particularly appropriate technology where the mix of explosives and other contamination types present would require the use of several remediation technologies to be effective. If space and geology permits, consideration should be given to creation of an on-site licensed landfill as this may significantly reduce environmental impact.

While cover/barrier systems can be effective for reducing or removing the risk of exposure of receptors to the contaminants, the contaminants are not destroyed and therefore future risks could persist.

On sites where explosives devices could be present there is always a concern that small numbers of these devices may have been dropped or dumped on the site, but not deliberately buried. For example detonators are very small and a few dropped on the ground could easily become covered by vegetation. To address this risk a so called ‘confidence scrape’ is often undertaken, as illustrated by Box 6.1.

Box 6.1 Confidence Scrapes - General Explosive Site Remediation Practice

It is common practice as part of a remediation strategy, to undertake a so called “confidence scrape” of near surface soils (e.g. the upper 300mm). This allows removal of vegetation cover and rapidly demonstrates the absence of explosive devices/fragments as a means of reassuring the public regarding a site.

In essence, should a discarded device or local spillage of explosives be present in the near surface soils, this would be removed as part of the confidence scrape excavation and disposal of surface soils. This not only helps to minimise the actual risk, but also reassures any purchaser or potential site user i.e. also addresses the perceived risks.

This is particularly important in residential development or open space land which will have regular and unrestricted public access and may be more cost effective than extensive metal detection or geophysical scanning.

Bentonite slurry and grout walls can, under appropriate geological and hydrogeological conditions, be used to contain groundwater contaminated by explosives, their degradation products or soil contaminated by more mobile explosives. Under certain conditions active containment can be considered using a ‘funnel and gate’ approach to focus groundwater towards part of the barrier wall where a sorbant material, such as activated carbon, traps the contaminants.

6.3.2 Biological based technologies

Biological based techniques can only be successful if the explosive contamination is of a small enough particle size (< 1 mm). Where larger discrete explosives particles are present e.g. in granules, flake or lumps, bioremediation is an inappropriate technique without some form of pre-treatment.

Ex situ Bioremediation

With the exception of certain initiator compositions such as lead azide or mercury fulminate, most explosive compounds are persistent in soil. However *ex situ* bioremediation using composting or biopile techniques employing microbes or fungi have been demonstrated to be viable techniques with many organic explosives. Verification analysis needs to demonstrate that the degradation process has not stopped at a metabolite which is itself toxic. Some literature recommends a two stage biodegradation for explosives such as TNT, where the first phase is anaerobic resulting in the reduction of certain nitro groups to amino groups before converting the process to aerobic biodegradation.

In situ Bioremediation

Certain organic explosives will respond to *in situ* technologies used to remediate organic contamination of groundwater, saturated and vadose zones of soils. However there is little experience of the use of such remediation techniques for explosives contamination in the UK. Assessment of the viability of any of the *in situ* technologies is analogous to that required for any other organic contaminant.

Phytoremediation (using plants to remove explosives from soil) is currently at the research stage. However the technique has the potential to be applied to various explosives in soil. The technology is likely to be most useful where contamination is low and diffuse, and where treatment times can be long.

6.3.3 Chemical based technologies

Chemical based technologies such as soil flushing, solvent extraction and surface amendments for the remediation of explosives contamination are currently untried outside the lab or pilot scale. However liming of soil to raise pH can be appropriate to reduce the mobility of the degradation products of metal salt explosives.

6.3.4 Physical based technologies

Soil washing or screening can be used to remove discrete solid explosives from soils. In addition soil screening may be an appropriate way of removing smaller explosives devices from soil. However in each case a detailed safety risk assessment should be conducted by experienced persons. Additionally it is technically possible to use soil washing technology to treat explosives contamination in soils chemically (e.g. by the addition of alkalis). However, currently such treatment is unlikely to be commercially viable.

6.3.5 Thermal based systems (including the use of fire and controlled explosions)

Thermal based systems can be divided into those utilising incineration, thermal desorption, controlled explosions and controlled firing.

Incineration

Open hearth burning of explosives and explosive devices is currently exempted from the Integrated Pollution Control (IPC) Regulations. The use of existing exempt facilities on explosives manufacturing sites is a possible remediation method for soils or explosives devices excavated from a site under remediation. However there are complex safety procedures and approvals required involving HM Explosives Inspectorate before such materials can be transported. Alternatively it may be the best practicable option to establish a temporary burning facility on the remediation site.

Incineration in IPC authorised facilities may be commercially non-viable, even if the operators are satisfied that it is safe. However a rotary kiln facility designed to destroy obsolete ammunition is operated by DERA at Shoeburyness. This facility can be used to destroy excavated explosive materials and explosives devices. Approvals to transport such materials are again required from HM Explosives Inspectorate.

Thermal Desorption

Use of thermal desorption technology to treat explosives contaminated soils is technically proven. However as explosives produce large amounts of NO_x, the thermal desorption plant will require appropriate acid gas scrubbing in order to operate within its IPC authorisation. As such plants are usually mobile, explosives contaminated soil can be treated on-site.

Controlled Explosions

The use of controlled explosions, either to decontaminate drains or areas of soil or to prove that there is no acute risk from explosives in soil, should only be considered in extreme instances and then only by employing explosives experts in the risk assessment and design of such projects. Examples of unsuccessful controlled explosions are illustrated by Box 6.2.

Box 6.2 Unsuccessful Controlled Explosions

Scenario 1

On a closed NG production plant in Canada a controlled underground explosion was set up to demonstrate that any NG in the soil did not pose an acute risk. The explosion detonated an unknown reservoir of NG trapped underground, resulting in a massive explosion and several fatalities.

Scenario 2

Detonating cord (a linear explosive used to transmit an explosive train in engineered explosions) was used to detonate significant explosive residues within drains on an explosives site. The resulting controlled explosion only succeeded in shattering the drain and moving the explosive residues into the surrounding soil.

The use of explosives to effect demolition or partial demolition of buildings is relatively common. However care is required in the use of such techniques on buildings known to be contaminated with explosives.

Controlled Firing of Buildings

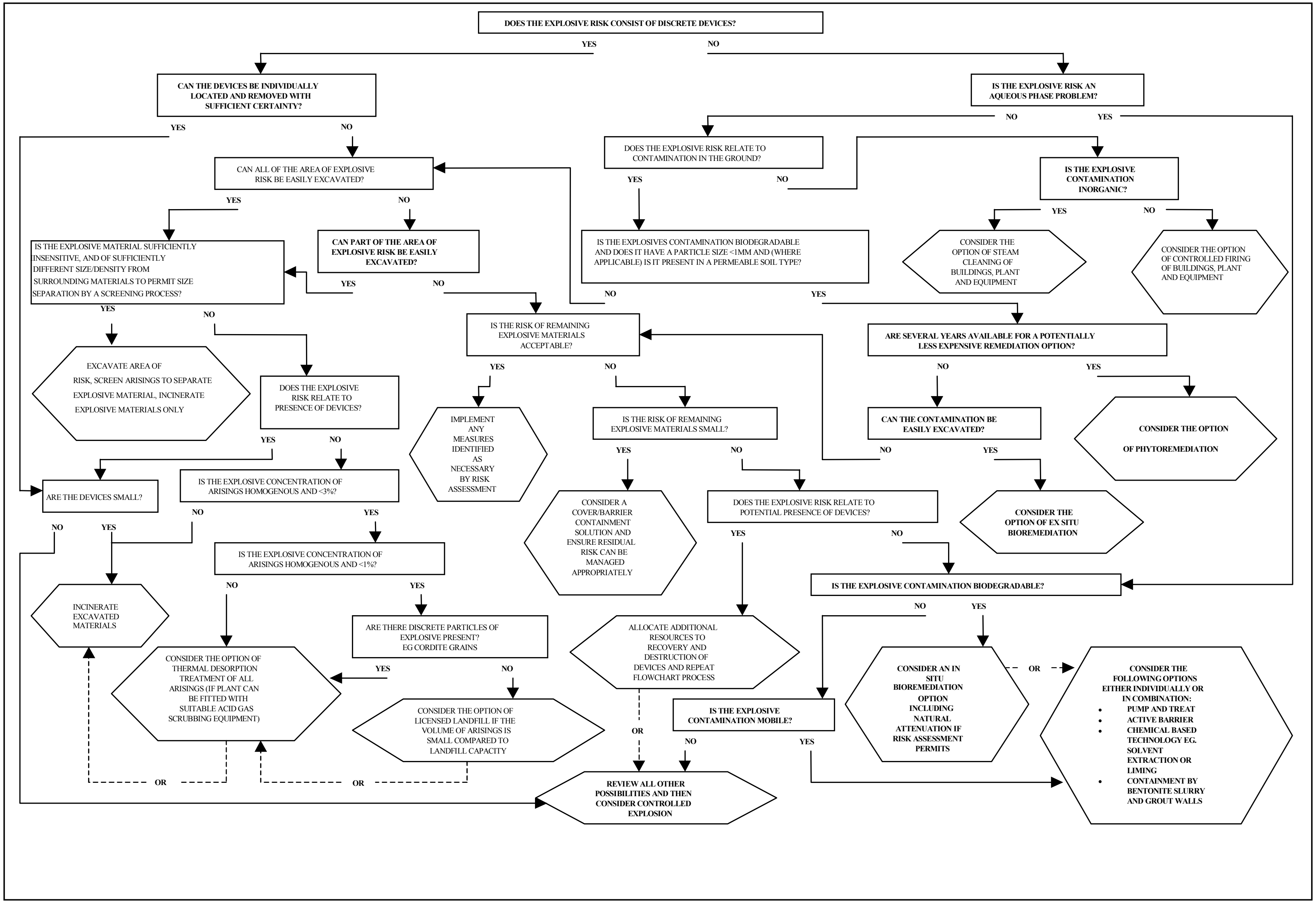
This is a recognised technique for the decommissioning (HS(G)36 – Disposal of Explosive Waste and the Decontamination of Explosive Plant) and decontamination of explosives contaminated buildings. The methodology needs to be carefully planned and the remediation should only be carried out by organisations experienced in the use of such techniques. The basis of the technique involves:

- removal of bulk or confined explosives;
- removal or control of asbestos;
- removal of materials likely to produce black or toxic smoke;
- development of a 'worst case' scenario risk assessment;
- the establishment of an exclusion zone;
- controlled firing of the building ensuring that heat penetrates all areas where explosives contamination is possible;
- temperature monitoring to ensure that adequate temperatures are achieved;
- conventional demolition of the structure.

6.4 Summary of Principal Remediation Technologies

The key issues relating to the main remedial technologies are presented in the following decision tree.

Figure 6.1 - Remedial Technology Decision Tree



6.5 Validation

The test methods used (whether on-site or at the laboratory) must be appropriate for the explosive contamination present (see Section 4 for details of appropriate analytical strategies). However, aside from this, no special validation procedures are needed for explosives contaminated sites.

7. HEALTH AND SAFETY

KEY QUESTIONS ANSWERED IN THIS SECTION

1. What legislation specific to explosives is relevant?
2. What working methods should be adopted for explosives sites?
3. What specialist equipment is required?

7.1 Scope

Health and safety considerations are a statutory obligation for work on all contaminated sites. Within this section only the specific health and safety guidance which relates to work on explosives contaminated sites is included. General guidance on health and safety issues for work on contaminated sites can be found in HSE (1991); CIRIA (1996); Thomas Telford (1993); and BDA (1992).

7.2 Specialist Legislation

Legislation relating specifically to explosives sites includes:

- the Explosives Act (1875) and (1923);
- the Control of Explosives Regulations (COER) 1991 & amendments;
- the Manufacturing & Storage of Explosives Regulations (2000).

The object of the above Acts and Regulations is to control the manufacture, storing, security, selling, carrying and importing of explosives for legitimate use. The above legislation controls and governs the health and safety on operational sites but does not explicitly recognise health and safety issues on derelict or sites undergoing decommissioning or redevelopment. Further relevant legislation includes:

- the Packaging of Explosives for Carriage Regulations (PEC) 1992;
- the Classification and Labelling of Explosives Regulations 1983; and
- Road Transport (Carriage of Explosives) Regulations 1989.

The above Regulations are all concerned with the correct packaging and transportation of explosives. Unless categorised prior to leaving site, all samples which may potentially contain explosives are subject to the same Regulations as for raw explosive materials. These Regulations are therefore equally as applicable for operational, derelict or sites undergoing decommissioning or redevelopment.

The HSE guidance note HS(G)36 Disposal of Explosive Waste and the Decontamination of Explosive Plant, also contains a section on decontamination of buildings.

7.3 Specialist Working Methods and Equipment

The overriding messages in the following sections are:

- the need for use of safety risk assessment as a standard tool;
- those carrying out risk assessments and work on explosives sites must be experienced and trained in handling and recognition of explosives;
- those working on operational sites must be aware of the Health and Safety Plan specific to the particular site.

7.3.1 Working methods

The following points give an indication of the issues associated with working on these types of site:

- Construction Design and Management Regulations (CDM) require that operatives are "competent" and trained in safety management. Operatives carrying out investigative and remedial works on sites where explosives may be encountered must have experience of this type of investigation, be familiar with the issues relating to explosives contamination and unexploded ordnance and have received adequate training in the handling of explosives;
- those carrying out investigations on sites with any risk from explosive devices must have training and experience in the recognition and safe management of such devices;
- a great deal of care and experience is needed when choosing the type of equipment for the investigation and the implications the equipment has for the health and safety of those using it must also be considered. This point is discussed in more detail in Section 4;
- of primary importance is the need to be vigilant, and if conditions change or unusual substances/items such as UXBs (unexploded ordnance bombs) are encountered - stop, review the situation and procedures and alter the health and safety plan accordingly;
- a contingency plan detailing the procedures which should be followed in the event of UXO (unexploded ordnance) being uncovered during the investigation should be included as part of the overall health and safety plan. Contingency plans should also detail procedures for the evacuation of a site, as well as a designated safety engineer;
- little is known about the toxicity of degradation products of explosives. Consequently, little is known about the health and safety implications arising from these substances, many of which are suspected to be explosive as well as toxic;
- smoking and use of 'naked flame' equipment should not be permitted anywhere on these sites, including sites where there is no longer any production of explosives;

- the use of communication equipment needs to be considered in the risk assessment. Certain explosives and devices, such as some initiators, can be initiated by emissions from mobile telephones or radio equipment;

- the investigation of buildings requires a specific approach and this should be highlighted in any health and safety plan if there are buildings on-site which are to be investigated. See also sections 4.3.2. and 5.2.2 which cover building investigations and evaluation of acute risk in greater detail;

- the possible presence of contaminants other than explosives should also be considered. Contaminants with specific health and safety implications, such as radioactive sources, chemical weapons and asbestos can also be found on explosives sites;

- during investigation or remediation work unauthorised persons must be excluded. Suitable and sufficient fencing and signs should be established at an appropriate position to provide a safe working area and to prevent any non-essential workers from entering the area;

- handling of samples is important; care should be taken not to accumulate materials since this would pose a greater explosive risk, also if unearthed explosives are left to dry they may pose a greater risk. The discovery of which may mean the requirement for emergency guarding and other security measures;

- contingency plans should be prepared.

7.3.2 Equipment

The level of Personal Protective Equipment (PPE) required will vary according to the results of the desk study and risk assessment. In general the PPE is the same as that which would be required for the investigation of a site with any organic contamination. It is essential that all operatives conducting the investigation have specialist training in the handling and sampling of explosive materials.

If the desk study/risk assessment finds adequate evidence of a fire hazard (e.g. a site contaminated with white phosphorus) the use of fireproof overalls should be considered.

Samples should be collected by hand using disposable gloves or by non-sparking tools. If an explosive device is uncovered or suspected then no attempt must be made to handle it unless properly trained.

7.3.3 Health and safety check-list

Has a risk assessment been conducted which specifically addresses the health and safety issues associated with the site in question - i.e. what explosives may be present?
Has a competent person been involved in the production/review of the risk assessment?
Will any of the legislation associated with explosives apply to the proposed works?
Does the Health and Safety Plan address the various contingencies in dealing with explosives UXB/UXO?
Is there a means of communicating all health and safety issues to all operatives, e.g. the importance of not handling any suspicious items and application of the 'no smoking/naked flame' rule?
Are there any issues which require specialist assistance, e.g. the prospect of buried munitions?

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Appendix A - Plates 1-3 Photographs Relating to Explosives Manufacturing and Processing Sites

Plate 1 Aerial Photograph Showing Layout of an Explosives Manufacturing and processing Site.

Plate 2 Cordite Propellant In The Ground

Plates 1-3 Photographs Relating to Explosives Manufacturing and Processing Sites

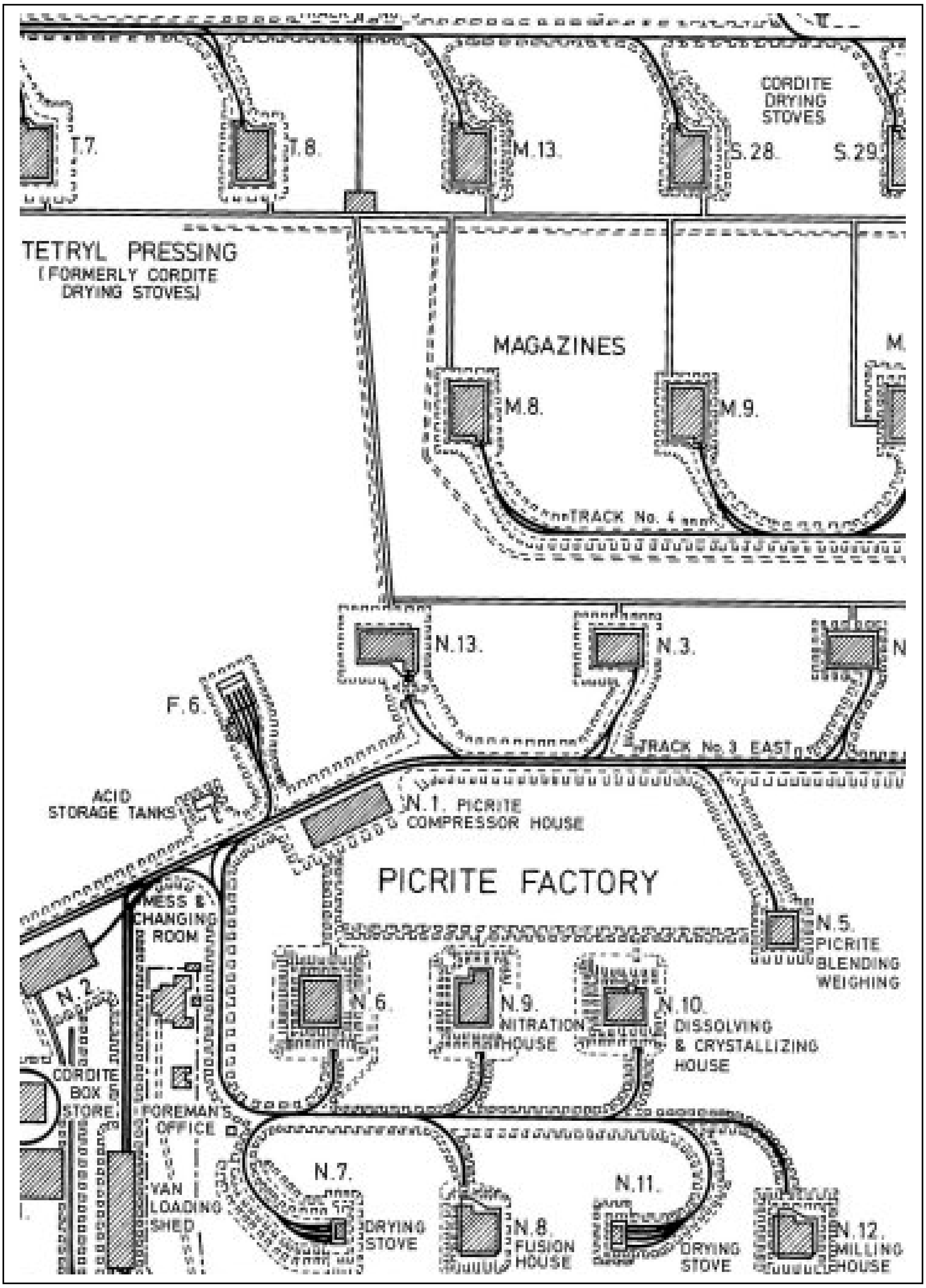

Plate 3 Typical Picrite Factory Site Layout

Appendix B - Tables

Table B.1 Historical explosives development

Explosive	Discovered by	Nationality	Date
Gunpowder	Roger Bacon	British	1246
Mercury Fulminate	Kunckel	German	1690
Picric Acid	Woulffe	German	1771
Nitrocellulose	Pelouze	French	1838
Nitroglycerine	Sobrero	Italian	1846
TNT	Wilbrand	German	1863
NC Propellants	Schultze	German	1864
Dynamite	Nobel	Swedish	1867
Ammonium Nitrate Mixes	Ohlsson/Norrbin	Swedish	1867
Tetryl	Mertens	German	1877
Cordite	Abel/ Dewar	British	1889
Lead Azide	Curtius	German	1890
PETN	Rheinisch-Westfaelische'	German	1894
RDX	Henning	German	1899
Tetrazene	Hoffman/ Roth	German	1910

Table B.2 Initial dates of the use of common explosive substances in the UK

Explosive	Date
NC	1846
NG	1867
Picric Acid	1874
Tetryl	1910
TNT	1914
RDX	1939
PETN	1939
HMX	1955
EGDN	not known
Picrite	1920s
HNS	not known

Table B.3 Chemical formulae, technical terms and common names for commonly encountered explosive compounds

Material	Gross Formula	Abbreviation	Common Synonyms	CAS number
Organic compounds				
Hexanitrostilbene	$C_{14}H_6N_6O_{12}$	HNS		20062-22-0
2,4,6- trinitrophenol	$C_6H_3N_3O_7$		picric acid, lyddite, melinite	88-89-1
Trinitrophenylmethylnitramine	$C_7H_5N_5O_8$	CE	tetryl, Composition Exploding	479-45-8
2,4,6- trinitrotoluene	$C_7H_5N_3O_6$	TNT		118-96-7
Cyclotrimethylene trinitramine (cyclonite, hexagon)	$C_3H_6N_6O_6$	RDX	research development explosive	121-82-4
Cyclotetramethylene tetranitramine (octogen)	$C_4H_8N_8O_8$	HMX	high melting point explosive	2691-41-0
Pentaerythritol tetranitrate	$C_5H_8N_4O_{12}$	PETN	Nitropenta	78-11-5
Nitrocellulose	$C_{12}H_{14}N_6O_{22}$	NC	Gun cotton	9004-70-0
Nitroglycerine	$C_3H_5N_3O_9$	NG	Glycerol trinitrate	55-63-0
Nitroglycol	$C_2H_4N_2O_6$	EGDN	Ethyleneglycol dintrate	628-96-6
Tetrazene	$C_2H_8N_{10}O$			109-27-3
Nitroguanidine	$CH_4N_4O_2$	NQ	Picrite	556-88-7

Material	**Gross Formula**	**Abbreviation**	**Common Synonyms**	**CAS number**
Inorganic compounds				
Lead azide	N_6Pb			13424-46-9
Silver azide	AgN_3			13863-88-2
Lead styphnate	$C_6HN_3O_8Pb$			63918-97-8
Barium styphnate	$C_6HN_3O_8Ba$			20236-55-9
Lead dinitroresorcinate	$C_6HN_2O_5Pb$?			13406-89-8
Mercury fulminate	$C_2HgN_2O_2$			628-86-4
Ammonium nitrate	NH_4NO_3			6484-52-2

Table B.4 Raw materials associated with the commonly encountered organic and inorganic explosives

Material	**Abbreviation**	**RD number**	**Raw materials**
Hexanitrostilbene	HNS		Stilbene, nitric & sulphuric acid
2,4,6- trinitrotoluene	TNT		Toluene, nitric acid (conc.), sulphuric acid (conc.), alcohol/benzene, aqueous sodium sulphide solution, dinitrotoluene, mononitrotoluene
Cyclotrimethylene trinitramine (cyclonite, hexagon)	RDX	RD1347	1: (1898)Hexamethylene tetramine, nitric acid (conc.), water 2: Ammonium nitrate, hexamethylene, tetramine, nitric acid, acid anhydride 3: Paraformaldehyde, ammonium nitrate, acetic anhydride, 4: Potassium amidosulphonate, formaldehyde, nitric acid, sulphuric acid bulk organic solvents for recrystalisation (e.g. acetone or cyclhexanone)
Cyclotetramethylene tetranitramine (octogen)	HMX		Hexamethylene tetramine, ammonium nitrate, nitric acid, acetic anhydride bulk organic solvents for recrystalisation
Pentaerythritol tetranitrate	PETN		Penterythrol, nitric acid (conc.), acetone
Nitrocellulose	NC		Nitric acid, sulphuric acid, cotton or cellulose from wood pulp
Nitroglycerine	NG		Glycerin , nitric acid (highly conc.) sulphuric acid (highly conc.), washed with water and alkaline soda solution
Nitroglycol	EGDN		Glycol (from alkaline hydrolysis of ethylene oxide), nitrogen, mixed acids
Picric acid			Phenol, sulphuric acid, nitric acid, water
Picrite (nitroguanidine)			1: Dicyanidiamide ammonium nitrate, sulphuric acid (conc.) 2: Calcium carbide, nitrogen, ammonium nitrate, sulphuric acid
Tetryl	CE		Monomethylaniline, dimethylaniline (DMA - formed by dehydration of aniline and methyl alcohol), sulphuric acid , nitric acid
Lead azides		RD1333, RD1339	Sodium azide, lead acetate or lead nitrate, acetic acid, sodium carbonate

Material	**Abbreviation**	**RD number**	**Raw materials**
Silver azides		RD1336	Sodium azide, silver nitrate, ammonia, acetic acid
Lead styphnate		RD1367, RD1303	Magnesium oxide, trinitroresocinol, lead nitrate, lead acetate, magnesium carbonate, polyvinyl acetate
Barium Styphnates		RD1340	Magnesium oxide, trinitroresorcinol, barium nitrate
Lead dinitroresorcinate (DNR		RD1337, RD1353	Sodium hydroxide, dinitroresorcinol, lead nitrate, lead acetate
Tetrazene		RD1357	Sodium nitrite, aminoguanidine sulphate, acetic acid
Lead azotetrazole		RD1355	Disodium azoterazole, lead acetate, ammonia
Mercury fulminate			Mercury, acetaldehyde, ethanol, methanol

Table B.5 Typical pyrotechnic substances that may have been produced on explosives manufacturing sites and their ingredients

Type	SR number	Typical ingredients
Delay compositions		
	SR11	molybdenum trioxide, boron, manganese
	SR39	tungsten, potassium dichromate
	SR57	boron, bismuth trioxide
Primer compositions		
	SR41	potassium nitrate, boron, silicon
	SR399	barium peroxide, acaroid resin, magnesium
	SR867	zinc stearate, magnesium, acaroid resin, strontium peroxide, bitumen
Igniter compositions		
	SR252	charcoal, silicon, potassium nitrate
	SR371	magnesium, acaroid resin, potassium nitrate
	SR800	magnesium, acaroid resin, potassium perchlorate
Signal/ flare compositions		
	SR91	magnesium, boiled linseed oil, strontium nitrate, chlorinated rubber
	SR232	magnesium, strontium oxalate, boiled linseed oil, potato starch, potassium perchlorate
	SR592A	mannitol, boiled linseed oil, sodium nitrate, magnesium
	SR700	boiled linseed oil, PVC powder, potassium perchlorate, barium nitrate, magnesium
	SR300A	potassium nitrate, boiled linseed oil, magnesium, barium nitrate
	SR572	magnesium, lithographic varnish, sodium nitrate, calcium oxalate
	SRE798	magnesium, sodium nitrate, thiokol, oxamide
Tracer compositions		
	SR372ABS	zinc stearate, strontium nitrate, beeswax, chlorinated rubber, magnesium, shellac, magnesium carbonate
	SR390	strontium peroxide, strontium nitrate, polymerised linseed oil, magnesium
	SR605A	shellac, magnesium, carnauba wax, strontium nitrate, strontium stearate
Smoke Compositions		
	SR223E	lead chromate, magnesium
	SR823	lead chromate, magnesium
	PN841	red phosphorus, butyl rubber
Notes: **SR = superintendent of research** **SRE = superintendent of research** **PN = Porton Down**		

Table B.6 Breakdown products of the more commonly encountered organic and inorganic explosives

Substance	Chemical Stability	Breakdown products	Comments
TNT	relatively stable	Amino dinitrotoluenes, (amino DNT) di-amino-nitrotoluenes, dinitrotoluene, mononitrotoluene	Breakdown products are not fully understood, may be toxic, but the toxicity data is incomplete. Breakdown products in water are often highly coloured (red).
HNS	Some instability in wet conditions	No data	
RDX	relatively stable	Mono, di and tri nitroso derivatives (followed by hydrolysis to substituted Hydrazines)	Breakdown products are not fully understood, may be toxic, but the toxicity data is incomplete.
HMX	relatively stable	Limited data, but likely to be similar to RDX	
Picric acid	relatively unstable in wet conditions	Forms impact-sensitive metal salts (Picrates) when in contact with certain metals. Biological attack proceeds via 2,4-dinitrophenol	Water soluble
PETN	relatively stable	Tri and di nitrate derivatives	
NC	stable	Nitrostarch and others - not known	Nitrostarch may be produced which is highly unstable and much more sensitive than the parent compound - Nitrocellulose
NG	relatively stable	Possibly includes di and monnitro glycerine	No data available on the products which may be encountered. Is a DNAPL
EGDN	relatively stable		Little known about the products which may be formed. Is a DNAPL
Tetryl / CE	unstable	Degrades to produce *equal quantities* of Picric Acid which in turn can form impact sensitive Picrates, also degrades to produce a characteristic red colouration in the soil, although it is not known what substances cause this.	Forms highly sensitive breakdown products
Lead azides	unstable in moist conditions	Lead and lead compounds	Stable in very dry soil
Silver azides	unstable in moist conditions	Silver and silver compounds	Stable in very dry soil

Substance	**Chemical Stability**	**Breakdown products**	**Comments**
Lead styphnate	unstable in moist conditions	Lead compounds	Stable in very dry soil
Barium Styphnates	unstable in moist conditions	Barium compounds	Stable in very dry soil
Lead dinitroresorcinate (DNR	unstable in moist conditions	Lead compounds	Stable in very dry soil
Tetrazene	unstable in moist conditions	Sodium compounds (not confirmed)	Stable in very dry soil
Lead azotetrazole	unstable in moist conditions	Lead compounds	Stable in very dry soil
Mercury fulminate	unstable in moist conditions	Mercury compounds	Stable in very dry soil