

Land Contamination:
Technical Guidance on Special Sites:
Chemical Weapons Sites

R&D Technical Report P5-042/TR/02

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This report (P5-042/TR/02) 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

Specific Technical Terms

Arsenicals	Chemical weapons formulations based upon arsenic.
Blister agent	Agent which causes injuries to the skin which have the appearance of severe blisters.
Blood agent	Agent which interferes with oxygen transport by the blood.
Burning grounds	The area of land used for the incineration of waste arising at a military site (including explosive, radioactive waste, excess fuel and clinical waste).
Bioaccumulation	The accumulation of a given substance within a living organism. It is possible for concentrations of a contaminant to be far greater in living tissue than in the surrounding environmental medium (bioconcentration).
Bioassay	The assessment of the response of a living organism to an environmental stimulus.
Carcinogenic	Having the potential to cause cancerous growth.
Choking agent	Substance which causes lethal lung damage.
Firing point	The point from which an armament is fired on a testing range.
Firing range	Area of land used to practice or assess munitions firing. A firing range may be used for basic training purposes, or for the assessment and development of new projectiles.
Impact point	The point at which a projectile lands on a firing range. On a proofing range (<i>q.v.</i>) the impact points may be erratically distributed, since the tested weapons are experimental, and therefore uncertain in flight.
Incapacitant agent	Alternative term for lacrimatory agents (see below) generally relates to tear gases.
Livens projector	This was a simple launch tube with an angled base plate from which cylindrical agent carrying munitions were fired; the term 'livens projector' refers to the munitions and the launch tube.
Lacrimatory	Having the potential to stimulate tears. CS gas is a common lacrimatory agent.

Mutagenic	Having the potential to cause genetic mutation. The significance of the mutation is dependent upon the cell affected. Mutation of somatic (non-sex) cells may not result in harm, although could lead to cancerous growth. Mutation of gametic cells (sex cells such as ova and sperm) will result in hereditary defects being passed to offspring.
Nerve agent	Chemical weapon designed to act upon the nervous system. Containing an organo-phosphorus group, nerve agents disrupt the transmission of nerve impulses, leading to paralysis and eventual death.
Precursor	Chemical which is modified to produce a desirable substance.
Proofing ranges	Firing ranges used specifically for the assessment of newly developed projectile armaments.
Pyrophoric	Pyrophoric compounds will combust upon contact with air. Pyrophoric alloys are those which will produce sparks when struck.
Simulant	Relatively low toxicity chemical which simulates the odour of a CW agent and so was used in identification kits.
Sniff kits	Vials containing small amounts of chemical weapon agents, used to train servicemen, air raid wardens and the home guard in the recognition of chemical weapons.
Sternutators	Vomiting agents.
Synergistic	Substances are said to be synergistic if their effect in combination is greater than the sum of their individual effects.
Urticant agent	Agent which causes intense pain.
Vesicants	Agents which have the ability to cause blistering, in particular of the skin, for example Mustard gas.
Vomiting agent	Agent which causes vomiting (otherwise known as sternutators).
Weaponised	Any material converted for use as a weapon is said to be weaponised. Thus, biological agents become weaponised when they are fitted to artillery projectiles.

Note: For details of the code names given to specific CW agents please refer to tables within the main text.

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 Chemical Weapons (CW).

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

- *Land on which the manufacture, production or disposal of chemical weapons has been carried out at any time*

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 (2000); 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.

All readers of this report should be aware that chemical weapons contaminated sites are potentially very hazardous and all work related to such sites should be undertaken only by suitably qualified and experienced experts.

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 a chemical weapon?
2. What is the likely distribution of contaminants within the ground across the site?
3. Which were the most significant contaminative processes?
4. Should other processes/contaminants be suspected which are not explicitly identifiable from available records?
5. How were waste/surplus chemical weapons managed?

SECTION 3: PHYSICAL AND CHEMICAL CHARACTERISTICS OF CONTAMINANTS

1. What are the main chemical and physical characteristics of the principal contaminants?
2. How do the principal contaminants behave in the environment?
3. If the contaminants are associated with artefacts (e.g. munitions, process equipment), are these recognisable and what do they look like in the ground?
4. What are the secondary contaminants which are often found?

SECTION 4: SITE CHARACTERISATION

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

SECTION 5: SITE EVALUATION

1. What are the primary pollutant linkages which should be assessed?
2. Which 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?

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. How can the remediation process be validated?

SECTION 7: HEALTH AND SAFETY

1. What specialist legislation is relevant?
2. What are the main hazards likely to be encountered?
3. What are the risks to health and safety of both operators and the public?
4. How can the major risks be managed to an acceptable level?
5. How can operators and the public best be protected?

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 <i>(for full definitions see the Contaminated Land (England) Regulations 2000)</i>	Reports in This Series of Particular Relevance to Each Special Sites Category						
	<i>P5-042/TR/01 MOD Land</i>	<i>P5-042/TR/02 Chemical Weapons</i>	<i>P5-042/TR/03 Explosives Manufacturing</i>	<i>P5-042/TR/04 Acid Tar Lagoons</i>	<i>P5-042/TR/05 Petroleum Refineries</i>	<i>P5-042/TR/06 Nuclear Establishments</i>	<i>P5-042/TR/07 Prescribed Processes Designated for Central Control</i>
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 a chemical weapon?
2. What is the likely distribution of contaminants within the ground across the site?
3. Which were the most significant contaminative processes?
4. Should other processes/contaminants be suspected which are not explicitly identifiable from available records?
5. How were waste/surplus chemical weapons managed?

2.1 Scope

This section presents a general overview of the key points relating to sites where chemical weapons (CW) agents may be encountered, the types of sites which 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 which have occurred on sites where CW agents have been manufactured, tested, stored or disposed of and which are likely to have resulted in ground contamination. Where appropriate the particular areas/activities within each of these groups of CW sites that are most likely to be associated with significant ground contamination are highlighted. Whilst CW sites can contain a range of contaminants the main agents of concern, and those which will be dealt with in detail in this section, are those which are associated with CW agents, their precursors and breakdown products.

2.1.1 What constitutes a chemical weapon

The definition of Chemical Weapons as given in Article 2, paragraph 1 of The Chemical Weapons Convention 1993 is as follows:

- “1. Chemical weapons means the following, together or separately:
- a) Toxic chemicals and their precursors, except where intended for purposes not prohibited under this Convention, as long as the types and quantities are consistent with such purposes;
 - b) Munitions and devices, specifically designed to cause death or other harm through the toxic properties of those toxic chemicals specified in subparagraph (a), which would be released as a result of the employment of such munitions and devices;
 - c) Any equipment specifically designed for use directly in connection with the employment of munitions and devices specified in subparagraph (b).”

Further details of this definition are given in Appendix A.

2.1.2 Overview of CW contaminated sites

General points regarding sites where CW may be encountered include the following:

- CW contamination is predominantly associated with the localised burial of weapons or burning pits, generally on current or former MoD (Ministry of Defence) and MoS (Ministry of Supply) land;
- the 1993 Chemical Weapons Convention (CWC), which came into force in April 1997, prohibits the development, large scale production, possession and transfer of CW, as discussed in Appendix A. The UK ratified the CWC and introduced the Chemical Weapons Act 1996 that incorporates it into UK law. The CWC does not cover munitions that have been buried in soils, whilst they remain buried. However, as soon as munitions have been found, they must be declared and destroyed under the terms of the convention;
- CW production occurred at a limited number of known sites in the UK from the period of the First World War (WWI) until the 1950s;
- the existence and general purpose of many CW production sites was known to the local inhabitants many of whom were employed whilst they were in operation. However anecdotal details of the activities carried out may often be inaccurate. Information on the present state of decontamination is often incomplete and difficult to locate. Clearance of a site was often a piecemeal process and decontamination would have been carried out according to the standards of the day;
- a wide range of contaminants is likely to be encountered on many of the sites other than those explicitly associated with CW production, most of which could also be encountered at other MoD sites. These are not discussed in detail in this report, and the reader is referred to Environment Agency R&D Technical Report P5-042/TR/01;
- chemicals, including solvents, which have been used to remediate CW sites with varying degrees of success may also have caused ground contamination. A large number of chemicals will have been formed by reactions between the CW agents, their decomposition products and the materials used for remediation. The result can be a complicated mixture of potentially harmful substances of unknown composition;
- establishing the period of operation of a particular site may assist in determining the CW agents which may be present in soils;
- lack of records is a major problem for these sites (as with other MoD sites). Information relating to activities, materials tested and produced (especially at R&D sites) and the location of disposal sites may not be available. The main reason for this was a past desire to keep such sites secret, especially during war time. A lack of awareness of the importance of such documents and of space to store them are also important factors. Much of the remaining information is held by the Defence Evaluation and Research Agency (DERA) at Porton Down. In addition the RAF Command Scientific Support Branch (CSSB) also has a comprehensive database of WWII RAF sites which held CW.

2.2 Distribution and Extent of CW sites in the UK

2.2.1 Key points

- Most of the bulk storage areas are known, although there may be a few that remain unidentified;
- the principal chemical agent production facilities have traditionally been located at the few sites listed subsequently in this section with research being undertaken at a number of other small scale facilities, namely Sutton Oak and Nancekuke (pilot plants) and DERA Porton Down Research and Development;
- a number of munition test firing ranges are known which are still contaminated with unexploded fired CW munitions;
- CW identification kits or “Sniff” kits (containing real CW agents) and improvised training aids may be found almost anywhere including locations outside of MoD land e.g. attics and cellars of residential properties;
- airfields and other similar bases were issued with chemical mines as defensive stores. Airborne CW munitions were deployed widely on RAF, USAF and to a lesser extent army bases throughout the UK. In wartime it was not unusual for them to be stored at roadsides and in woods not enclosed by MoD perimeter fencing. Many of these munitions were buried at the end of the war and are still being uncovered;
- CW agents in containerised or weaponised forms may potentially be present on any MoD site. Recent studies (described in a restricted report) have revealed that during WWII CW munitions were distributed widely and not concentrated at the production and storage sites and the few forward filling depots as had previously been thought;
- CW have been disposed of by burying or burning on many MoD sites.

2.2.2 Uncertainties

- There is a general lack of records detailing both the location of sites and the specific areas within sites where CW contamination may be present. Identification can therefore be a major problem. Liaison with the relevant service authorities or DERA Porton Down is recommended in all cases where there is doubt;
- many munitions and agent storage areas are known, but the precise location of many others is uncertain and a considerable number may not yet have been identified;
- in addition to production and research sites, CW contamination may be present in soils at sites which have no current connection with the MoD. During the Second World War (WWII) production and bulk storage were the responsibility of the Ministry of Supply (MoS) which later became part of MoD as the Procurement Executive (PE). Many former MoD (and MoS) sites have been returned to private ownership or to other Government

Departments. Some sites, especially during WWII, were never owned by MoD, or MoS but were simply requisitioned and returned to their owners at the end of the war;

- during WWII it is probable that chemical weapons or agents were filled, stored, handled or disposed of at a large number of military or former military sites around the UK. Much of this activity was associated with training which would have taken place at almost every military site or Home Guard post. Generally, only relatively small quantities of CW agent would have been involved. Larger quantities (tens of litres) of Mustard were used at military bases to practice decontamination. However RAF research indicates that much of this training was undertaken using ‘training mixtures’ rather than actual CW agents. The RAF also consider that much of the CW used in training exercises would have been inactivated by the decontamination processes involved in the training exercises. It is not known how wide-spread this type of training was, but it is likely to have taken place, for example, at the majority of airbases;
- Identification kits were widely distributed and disposed of locally, usually by burying;
- Thousands of filled aircraft bombs were dispersed widely to all types of airfield, and to woods alongside minor roads, as a matter of policy in case of air attack.

2.2.3 Unidentified sites

For some sites, there may be few records available to identify the former function of the site or the activities which may have been carried out. This is often the case with sites which passed back into civilian hands many years ago, such as those which were sold off shortly after the end of WW II.

Particular issues on unidentified sites are:

- these are likely to have been returned to previous owners in haste at the end of the war and there may have been less regard for disposing of materials in a controlled manner;
- intact munitions may be present;
- a wide range of materials may have been disposed of;
- there is also an explosive risk if munitions are intact – further details on this issue can be found in Environment Agency R&D Technical Report P5-042/TR/01 and R&D Technical Report P5-042/TR/03.

2.3 Key Site Features

The principal types of sites where CW contamination may be encountered are as follows:

- research and development (R&D) facilities including laboratories;
- proofing ranges;
- production sites/factories (chemical companies carried out the work under contract to the MoS) including mixing, filling, and decanting areas;
- storage areas (for both CW agents and filled munitions);
- operational military sites e.g. wartime airfields;
- unidentified sites.

Within each of these type of sites CW contamination is known to be particularly associated with the following features:

- laboratories;
- production - mixing, filling, decanting areas;
- proofing ranges/general firing ranges;
- storage areas;
- drainage systems;
- waste disposal areas including:
 - ponds, wells;
 - burial sites/pits;
 - burning grounds/pits;
 - Mustard pits.

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

The following matrix provides an initial indication of which of these features is likely to be of interest on each of the site types:

Table 2.1 - Matrix of features and site types

Feature	Site Type				
	R&D	Ranges	Production	Storage	Operational
Laboratories	✓		✓		
Mixing, Filling, Decanting Areas	✓		✓		
Ranges	✓	✓			
Storage Areas	✓	✓	✓	✓	✓
Drainage Systems	✓		✓	✓	
Ponds, Wells	✓	✓	✓	✓	✓
Burial Sites/ pits	✓	✓	✓	✓	✓
Burning Grounds/ pits	✓	✓	✓	✓	✓
Mustard Pits			✓	✓	

CW research, production, munition filling, storage and destruction were all performed in a manner consistent with the quality, health and safety standards of the day. Many of the accepted and commonplace practices which were employed in the past now seem arcane with very little, if any, consideration of matters such as the environment or human health.

2.3.1 Laboratories

Key points relating to CW contamination at CW laboratories and research and development (R&D) sites include:

- generally these sites involved the small scale production and testing of new agents and mixtures;
- the main laboratories are located at Porton Down. Some satellite establishments have also been used. R&D has always been done at Porton Down whilst the main production sites such as Springfields and Valley had their own laboratories. Sutton Oak and Nancekuke were rather different in so far as they were pilot scale production sites for many agents including nerve agents. They also made pilot scale batches of antidotes etc as required and thus needed more comprehensive laboratory facilities. Storage sites had “laboratories” where minimal testing was done. Quality assurance work was done at the Royal Ordnance Factories (ROF) Chorley laboratories;
- testing was carried out both in the laboratories and at outdoor test sites using CW agents. Some of the substances produced may have harmful decomposition products. In addition, reactions between compounds may have generated additional toxic materials which may be present in soils;

- R&D sites will have carried out a variety of tests with a range of munitions, explosives and equipment in addition to protective equipment.

2.3.2 CW production - mixing, filling and decanting areas

Key points relating to CW contamination at CW production - mixing, filling and decanting sites include the following:

During and After WWI

- Following the first use of CW by the Germans during WWI, the UK developed both offensive and defensive CW capabilities including an active research establishment at Porton Down. Information on WWI production sites is limited;
- given the range of materials synthesised, and the relatively small scale on which most of them were made, it is likely that much of the work was performed in universities, notably London, and by commercial chemical manufacturers, with the required equipment and chemical process expertise;
- it is unlikely that chemical plants were built specifically for CW production, and those that were would have been converted to commercial use (rather than destroyed) after the war;
- in 1925 the UK signed the Geneva Convention and subsequently disposed of its existing stocks of charged CW munitions (mostly by sea dumping).

Approach of WWII

In 1936 plans were set in motion for the development of a production plant for Mustard at Sutton Oak. As political tension increased, construction of a further Mustard plant was begun at Randle in 1938 and full capacity achieved in 1939. The creation of the Ministry of Supply (MoS) in 1939 formed a focus for the production and storage of CW agent and munitions. At this time the 500 tons stock of Mustard was filled into munitions.

During WWII

- Although CW were not used during WWII, considerable stocks of bulk agent and munitions were built up between 1939 and 1945. The following production and storage facilities were established by the MoS during WWII:
 - Randle, Springfield, Valley, Rocksavage and Hillhouse (all these sites had munition charging facilities) for agent production;
 - Rocksavage, Hillhouse, Wade and Roydmills for intermediate production;
 - Valley for bulk storage;

- in addition, there were several military controlled depots with munition charging facilities and storage capacity for either 500 or 1500 tons of bulk agent. These were the Forward Filling Depots (FFDs) at Barnham Heath, Melchbourne Park, Norton Disney (Swinderby), Lord's Bridge and West Cottingwith;
- the main dedicated WWII CW production facilities are known, though again it is believed that a number of chemicals, both precursors and the CW agents were also supplied to the MoD and MoS by commercial chemical manufacturing companies.

Post WWII 1946-56

Wade was disposed of immediately together with Springfield (to MoS Department of Atomic Energy). Production capacity at Valley and Roydmills was disposed of soon after. The charging and phosgene production capacity at Rocksavage was disposed of and Hillhouse was leased to ICI. Stocks of Mustard were retained with the intention of replacing them with nerve agents but retention of an offensive CW capability was abandoned before they could go into production. Some pilot scale nerve agent production took place at Sutton Oak but this was closed and moved to a new purpose built site at Nancekuke in 1949.

After Ministerial approval in 1956, the MoD finally gave consent for disposal of the remaining Mustard stocks and munitions in 1957. Munitions were sea dumped and bulk agent taken to Randle for burning. Mustard, lewisite and munitions were also disposed of by open pit burning at many of the military (mainly Army and RAF) storage locations. Research into the nerve agents continued at a low level. Since Nancekuke closed in 1980, there is no longer any CW production capability in the UK. Large scale production would now be contrary to the terms of the 1993 Chemical Weapons Convention (CWC).

Most of the WWII production plants were decommissioned at the time that they were closed down or shortly afterwards. The extent of decommissioning varied and ranged from decontaminating the storage tanks and sealing the buildings, to stripping out the chemical plant and re-using the buildings, to total removal and levelling of the site. This work was done to the standards of the day and, in some cases, intact CW agents and contaminated equipment are still being discovered.

Further details on individual production, storage and filling facilities are given in Boxes 2.1 and 2.2.

Box 2.1 Principal CW Production Facilities

Randle

- Located at Wigg Island on the southern bank of the River Mersey to the north of Runcorn, this was the site of a purpose built production facility dating from the late 1930s. The plant produced principally Mustard until the end of the WWII although the plant was kept in an operational condition until 1956. During the 1950s the plant was used to manufacture ethylene glycol. Randle was also the site used for the destruction of 6000 tons of Mustard and other vesicants during the late 1950s in an incineration plant.

Rocksavage

- An ICI operated plant also located in Runcorn which was used for the production of chlorine, bleaching powder (used for decontamination of Mustard) and phosgene.

Wade

- An ICI factory located at Northwich which produced chlorine, bleaching powder and alloprene (chlorinated rubber).

Royd Mills

- Located near Huddersfield this ICI plant produced thiodiglycol an intermediate for the production of Mustard. Ethylene glycol was also produced at the site. Prior to the outbreak of WWII, the intermediate for Mustard had been produced at the nearby ICI Dalton plant.

Springfields

An ICI operated Ministry of Supply plant located approximately six miles west of Preston. It housed two production plants designed for a total of 600 tons of vesicant per week. The site also had storage capacity for 65 tons of Lewisite or Larmine (bromo benzyl cyanide). This was the first site to be established under the UK's atomic energy programme in 1946 and is currently operated by BNFL.

Hill House

- An ICI plant near Fleetwood used for the production of chlorine for use at the other production plants detailed above.

Source: T I J Toler Poison Gas Manufacture in the UK, from After the Battle

Box 2.2 Principal Bulk Storage and Forward Filling Depots (FFD's)

Bulk Storage

Valley Works

- Shortly before the start of WWII the former Bryn Celyn lead and zinc mine at Rhydymwym, near Mold in North Wales was taken over by the Ministry of Supply for the bulk storage of CW, mainly Mustard. The site covered an area of approximately 90 acres and comprised a series of tunnels cut in to the rock. There were four main chambers which housed 78 lead lined steel storage tanks of 55 and 65 tons capacity. In addition to the storage Valley was also used for manufacture and weapons filling. In 1941 it was producing 266 tons of Mustard per week. The site is also understood to have been involved in the early nuclear programme in the 1940s.

Forward Filling Depots

There were a total of five FFD's: Nos 1 and 2 controlled by the US Army Eight Air Force Service Command and the remainder by the RAF.

No 1 Barnham Heath

- Located about 4 miles south of Thetford. It had underground storage for 1,500 tons of Mustard and facilities for filling spray tanks and 65lb bombs.

No 2 Melchebourne Park

- Located about 10 miles north of Bedford it had similar facilities to Barnham Heath.

No 3 Norton Disney (Swinderby)

- Although described as located at Norton Disney (a village 8 miles south west of Lincoln) it was in fact close to the Bomber Command airfield at Swinderby. It had storage for 500 tons of Mustard and facilities for filling 65lb bombs.

No 4 Lord's Bridge

- Located 5 miles south west of Cambridge with similar facilities to Norton Disney.

No 5 West Cottingworth

- Located 8 miles south east of York with similar facilities to the other RAF FFD's.

Source: T I J Toler Poison Gas Manufacture in the UK, from After the Battle

Box 2.3 Scenario: Lord's Bridge Explosion

In January 1955 a 25 foot diameter, 25 deep underground concrete tank containing Mustard diluted with benzene (coded as Y25) exploded as a result of work on the surface with an oxy-acetylene torch. This resulted in a major explosion and the distribution of Mustard vapour over the surrounding countryside. After the resulting fire was extinguished the remaining Mustard in the tank was transferred to another tank and basic decontamination was carried out using bleaching powder.

Source: T I J Toler Poison Gas Manufacture in the UK, from After the Battle

Box 2.4 Scenario: CW Production Site Decommissioning

At one CW production site all equipment was removed following closure but the buildings and storage tunnels still remain. Contaminated equipment that could not be decontaminated readily or re-used was buried on site in disposal pits. The drainage system remains intact but is known to be leaking and broken in places. CW munitions have been recovered from some of these burial sites and it is almost certain that more are yet to be discovered.

Source: T I J Toler Poison Gas Manufacture in the UK, from After the Battle

2.3.3 Proofing/firing ranges

Key points relating to CW contamination at proofing /firing ranges include:

- trials of prototype weapons occurred, mainly at Porton Down, the detailed components of which are unknown as there are no complete records of the precise types of weapons tested;
- biodegradation and breakdown products of the CW agents are likely to be present in soils, for example, arsenic compounds from lewisite breakdown;
- some of the agents concerned are highly volatile and evaporate and/or react rapidly with soil moisture given the correct conditions, for example, a gaseous CW agent such as phosgene will not be found in the soils unless it is present in an intact munition or other container;
- some CW agents are more persistent and these types, notably H (sulphur mustard) and T (oxygen mustard), are likely to remain intact in the soil;
- residual risks can remain for many years on old firing ranges which can include intact CW agents and breakdown products released from properly functioning munitions;

- CW testing was carried out on test ranges at R&D sites, and on permanent or temporary firing ranges at some other MoD sites. Some of these ranges or test areas are no longer owned by MoD;
- conventional munitions and explosives will be present and as such contaminants will include:
 - explosives - organic explosives residues, breakdown products, also metals from the breakdown of inorganic explosives;
 - pyrotechnics;
 - propellants;
- unexploded munitions are likely to be present.

Unexploded CW Munitions

Test ranges are likely to be areas of particularly high risk since a wide range of munitions including the full range of weaponised CW agents could be present. Fired munitions of any type are inherently unsafe since the fuse safety mechanisms are deactivated during firing and such items, (known as ‘blinds’), remain intact only because they have malfunctioned. Depending on the munition and fuse type, blinds have the potential to function (i.e. to release the CW agent) when disturbed and **should be handled by expert explosive ordnance disposal (EOD) operators only**.

Functioning blinds will release the CW agent as originally intended and, depending on type, may present a risk to others not in the immediate vicinity of the release. Old CW munitions tend to leak, especially when handled, and can present a severe risk of injury to persons coming into contact with them even if they do not explode. **Intact munitions of any type when found should immediately be reported to the police who will call the appropriate EOD experts.**

Other key points in respect to unexploded CW munitions include the following:

- depending on munition type, firing conditions and soil consistency, munitions bury to different depths. In general, larger heavier munitions go deeper but are easier to find with metal detectors;
- properly functioning CW munitions of all types are designed to release their contents from surface craters of typically half to one metre in depth;
- blinds can penetrate much deeper and large aircraft or mortar bombs can be found, for example, in solid chalk at depths of several metres.

2.3.4 CW storage sites

Key points relating to CW contamination at sites where CW filled munitions may have been stored include:

- UK storage of CW ceased following a decision by the UK Government to abandon these weapons in the 1950s;
- storage of CW is prohibited under the terms of the 1993 Chemical Weapons Convention. This followed on from the 1925 Geneva Convention which was a voluntary agreement and so did not prohibit the storage or possession of CW;
- CW agents were stored in a variety of ways, dependent on the site, the munition type and the resources/facilities which were available. Both above and below ground storage facilities were used;
- filled CW munitions were stored at various MoD sites across the country, especially during WWII;
- many RAF airfields and some army bases stored CW agents during WWII;
- ad hoc storage in woods and along country roads was also used in order to disperse this key strategic reserve and protect it from air raids and reconnaissance;
- fewer, if any, naval bases stored CW agents (the MoD is currently unaware of any CW storage on naval bases);
- it is likely that a large number of MoD sites may have unrecorded areas where CW filled munitions were stored during WWII and where disposal was carried out;
- many munitions from the WWI and WWII eras often began to leak with age during storage and hence were generally buried in the ground as a result.

As is apparent from the points made above, it is very difficult to identify all the locations where CW may have been stored in the past. During wartime, records of variable quality were kept but were often not retained after the war due to a lack of space and the disbanding of many units and establishments. Some consolidation and summary reports were prepared but much of this work was never completed. These reports were internal to the MoD and any request for such information should be directed to DERA Porton Down or MoD.

2.3.5 Drainage systems

Key points relating to CW contamination in drainage systems include the following:

- drainage systems invariably lead either to soakaways or into water courses and/or open bodies of water so any CW contamination has the potential for spreading into sensitive areas;

- WWII era toxic drains were usually constructed of salt glazed terracotta sealed together with jointing compounds which tended to leak in use. Examples are known where toxic drains failed catastrophically during the operation of the plant and had to be replaced with the old contaminated drains left in place;
- most, if not all, of these drainage systems remain in place and probably still contain live CW agents, especially in sumps and joints;
- seepage from joints and cracked drains will also have resulted in locally contaminated soil conditions which can persist for many years;
- many of these toxic drains were positioned at shallow depths and the modern practice of deep ploughing has resulted in at least one example where such a drain has been totally broken up and incorporated into the surrounding soil which is currently used to grow crops.

2.3.6 Ponds and wells

Key points relating to CW contamination in ponds and wells include the following:

- although features such as ponds and wells were not used as official disposal routes for CW, in practice they were frequently used for casual disposal of a variety of items including CW munitions;
- ponds are relatively easy to investigate if they can be drained since deposited items are usually found on the surface or in near surface mud in a strictly defined area. A visual search supplemented by raking is probably sufficient supplemented with magnetometry if necessary;
- a number of examples are known of wells that have been used historically to dispose of CW munitions and related CW material none of which have been investigated;
- disposal of CW in wells potentially represents a serious risk to groundwater since, by definition, the deposited items are located directly into the aquifer;
- if wells are still open, and where safe access can be guaranteed, then a manual search using divers is very effective for identifying CW munitions. Preliminary testing of water quality for evidence of CW should be considered and the use of remote inspection cameras etc. should be considered prior to manual searching for munitions.

2.3.7 Waste disposal areas: burning grounds, disposal areas and Mustard pits

Normal Method of Disposal

The recommended method of disposal for CW munitions was deep sea dumping. Land burial was supposed to be used for temporary disposal only as a method of making safe suspect, and especially, leaking, items. In practice, land burial became the normal disposal route for small

numbers of items and sea dumping was used mainly when large quantities of surplus munitions were being disposed of in a major operation.

All CW munitions and containers tended to leak and, because of the extreme hazard associated with handling and transporting them, many disposals would have taken place on site by burning and burying. The only time that items would have been removed from the site would be if they could be used elsewhere or had significant scrap value e.g. brass cartridge cases.

The consequence of this is that CW munitions, and related items, may well be encountered at most current and many former military sites and not just the few known specialist sites.

After the two world wars, most CW munitions surplus to requirements were disposed of by sea dumping. During the 1950s, the UK unilaterally disposed of its CW stockpile by further sea dumping of munitions. Bulk agent was burnt at Randle in a primitive incinerator without pollution abatement. Other sites had less sophisticated disposal facilities. Most burning was done in open pits or on the surface in designated areas. Hence the terms burning pits, burning areas and burning grounds.

Some limited studies have been carried out on the types, quantities and toxicities of the decomposition products produced in these uncontrolled processes. What little is known is summarised in the following sections but there is an urgent need for more research, especially toxicological research. Until this work can be done it is strongly recommended that all CW agent residues are regarded as being highly toxic and potential carcinogens. Consequently appropriately conservative levels of protection should always be provided for workers involved in intrusive operations and suitable measures taken to safeguard the public.

Burning Grounds

In addition to the contaminants discussed in Environment Agency R&D Technical Report P5-042/TR/01 in this series, burning grounds could also contain CW agents. R&D sites are likely to have produced a wide range of substances, many of which were never weaponised. These sites, and in particular burning grounds and disposal areas of the sites, could be contaminated with all of the CW agents discussed in Section 3 including a range of the more unusual compounds for which there are no records/sparse data relating to their toxicity.

Disposal Areas

In addition to the dedicated burning grounds, CW sites will often have had the following types of disposal areas:

- incinerators - particularly at the larger sites. In some instances CW would have been disposed of in 'general purpose' incinerators together with other waste types. There may also have been dedicated incinerators for the destruction of CW agents. The ash from these facilities will usually have been disposed of within the site and as discussed above can contain a wide range of breakdown products;
- landfills - possibly contaminated with CW - particularly at older sites;

- disposal grounds and dedicated CW disposal areas - such as Mustard pits.

In addition to traces of CW agents and breakdown products, intact munitions and drums of CW agents may have been buried on-site, either in dedicated areas or in some cases (historically) in combination with domestic refuse on MoD landfill sites.

Mustard Pits

Attempts were generally made to decontaminate or partially destroy the CW agents at the time of disposal. A good example of this is Mustard, where the method of disposal involved digging a large pit, lining it with dry bleach, tipping in drums of Mustard/filled breached munitions, pouring more bleach over the top which, due to the heat of reaction generated, would then cause the waste to be set alight.

A number of points need to be made with regard to disposal pits of this nature:

- Mustard is a particularly important example since large quantities of this chemical were produced and disposed of in this manner, especially at the end of WWII;
- the efficiency of the methods varied. In many cases, some Mustard would have remained in the pits unburnt and unchanged;
- other CW agents may also have been disposed of in ‘Mustard pits’;
- the breakdown products (degradation products) may be toxic - for example pyrolysis of Mustard gives rise to dithianes and thioxanes. Arsenical CW agents such as lewisite degrade to leave inorganic arsenic compounds which are still toxic;
- the chemical reactions which take place in disposal pits are highly complex, with the specific burning conditions and the materials used for detoxification having a marked effect on the substances produced. This can lead to the production of highly toxic and persistent substances such as dioxins;
- other CW agents may have decomposed to produce more or less toxic products. For example phosgene decomposes to produce non-toxic compounds such as carbon dioxide and hydrogen chloride. However, phosgene could also be present in intact drums or munitions and as such would be unchanged and potentially hazardous;
- as with other disposal areas on any MoD site, consideration has to be given to the possible presence of other hazardous substances, in particular explosives and radioactive contaminants;
- in some circumstances CW agents may have been co-disposed on-site with "domestic" type refuse, either by burning or burial. For example, during the recent clearance at Winterbourne Gunner, munitions were found in the “domestic” waste dump along with building rubble, tin cans, bottles etc.

The decomposition products which can be formed under various conditions are presented in Table B.4 of Appendix B.

Disposal on Civilian Sites

In addition to disposal on MoD land, as discussed earlier, there is a possibility that CW substances may be encountered on civilian land. There are three particular situations where this may be the case:

- land which was formerly MoD land, or formerly used for production or disposal of CW agents and the munitions containing them;
- land which was used for dispersed temporary storage of CW during wartime; and
- land on which CW sniff kits have been disposed of.

Sites where sniff kits have been buried are the most difficult to identify. Thousands of sniff kits were issued to a broad range of people including servicemen and women, and civilians such as air raid wardens and members of the home guard. Sniff kits usually consisted of a set of small vials containing a range of CW agents and were used for training in the recognition of CW in preparation for possible CW attacks. They were often buried when no longer required, i.e. at the end of WWII. In some cases they were buried in domestic gardens or in areas where the home guard were stationed. Some are still being encountered intact in cellars/lofts or are discovered when land is developed. Photographs showing selected sniff kits are included at the end of Section 3.

A table connecting the principal pollutant linkages with probable contaminants and processes involved in the development, production testing and storage of CW is presented as Table 2.2.

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

PRINCIPAL POTENTIAL POLLUTANT SOURCE	ASSOCIATED CONTAMINANTS	PROCESS/ACTIVITY
Harm		
Acute and chronic toxicity hazards from shallow soils contaminated with high concentrations of CW	Wide range of CW agents, precursors and degradation products may be encountered.	<ol style="list-style-type: none"> 1. Production areas 2. Research facilities 3. Firing ranges 4. Storage areas 5. Disposal pits 6. Burning grounds
Chronic toxicity hazards from shallow soils contaminated with low concentrations of CW	Wide range of CW agents, precursors and degradation products may be encountered.	<ol style="list-style-type: none"> 1. Production areas 2. Research facilities 3. Firing ranges 4. Storage areas 5. Disposal pits 6. Burning grounds
Unexploded CW ordnance (explosive and chemical hazards)	Principally Mustard (H and HT mixtures) and phosgene plus degradation products.	<ol style="list-style-type: none"> 1. Firing ranges 2. Storage areas 3. Disposal pits 4. Burning grounds
Sniff kits (identification kits)	Wide range of CW agents may be present in small quantities but sufficient to be hazardous.	<ol style="list-style-type: none"> 1. Were widely issued during WWII and so may be found in almost any location including cellars and attics
Pollution of Controlled Waters		
Leaching from contaminated soils	Thiodiglycol (TDG) is the main hydrolysis product of Mustard and is more soluble in water compared to Mustard. Dithiane and thioxane are the principal decomposition products following incomplete combustion in open pits. Dioxins and other complex compounds are possible especially when bleach was also used. High levels of arsenic compounds are known to be present at some sites.	<ol style="list-style-type: none"> 1. Production areas 2. Research facilities 3. Firing ranges 4. Storage areas 5. Disposal pits 6. Burning grounds

3. CHEMICAL AND PHYSICAL CHARACTERISTICS OF PRINCIPAL CONTAMINANTS

KEY QUESTIONS ANSWERED IN THIS SECTION

1. What are the main chemical and physical characteristics of the principal contaminants?
2. How do the principal contaminants behave in the environment?
3. If the contaminants are associated with artefacts (e.g. munitions, process equipment), are these recognisable and what do they look like in the ground?
4. What are the secondary contaminants which are often found?

3.1 Scope

This section presents an overview of the chemical weapons that may be encountered at the sites discussed in Section 2. Chemical warfare never took place in the UK so, in the main, the only munitions and CW agent residues likely to be encountered on the majority of sites are of British manufacture.

The exceptions to this would be sites where the USAAF stored CW during WWII and the North Wales location at which German CW munitions retrieved from Germany were stored at the end of the war (further details of the North Wales location could not be provided by DERA although this is likely to be Valley - see Section 2 for additional details).

This section includes information relating to chemical and physical form, toxicity and behaviour of CW agents in the environment. Key information on the main CW agents is given in Section 3.2. Section 3.3 contains information on the principal raw materials involved in CW production whilst Section 3.4 contains key information relating to the breakdown products of CW and the factors which influence CW degradation in the environment.

Further technical details which support the summary information presented here are given in Appendix B.

Table B.1 in Appendix B provides details of the synonyms and chemical names of these substances.

Table B.2 in Appendix B presents the following physical characteristics of the principal CW agents:

- appearance;
- odour;
- solubility;

- persistence;
- stability in storage/environment.

Table B.3 in Appendix B lists some of the more important raw materials used for the production of CW agents.

Table B.4 in Appendix B provides a list of the known breakdown products of the CW agents previously discussed. The reader should be aware that this is not a definitive list, and new breakdown products are being discovered with each new investigation.

Table B.5 in Appendix B also gives examples of breakdown products which may be formed as a result of historical disposal activities.

Specific chemical parameters that provide valuable information relating to the behaviour of these compounds in soils can be found in the References (Section 8). In most cases the available physico-chemical data for these substances will be incomplete.

3.2 Chemical Characteristics of Principal CW Contaminants

3.2.1 Contaminants associated with chemical weapons

CW agents can be classified in various ways, such as their mechanism of action, their toxic effects or their persistency.

The chemical compounds described relate to the following categories:

- the main British weaponised CW agents from the two world wars (WWI and WWII Tables 3.1 and 3.2) respectively;
- the wider range of CW agents expected in German WWII weapons and hence included in Home Guard identification sets (or ‘sniff kits’) (Table 3.3);
- an even wider range of compounds investigated at research sites. Representative compounds are identified in (Table 3.4) but this list is by no means exhaustive.

In addition to the explicit CW agents presented in the table, pyrotechnic and explosive charges associated with dissemination of the agents may also be found incorporated into munitions or as separate items on sites used for the assembly of munitions. For further details refer to Environment Agency R&D Technical Report P5-042/TR/01 and R&D Technical Report P5-042/TR/03.

Table 3.1 - Principal groupings of WWI CW agents

PRINCIPAL TYPES OF CW AGENT	COMPONENT SUBSTANCES	COMMENTS
MUSTARD AGENTS, VESICANTS (cause physical injury, vesicles or blisters)	Sulphur mustard (H) alone or in various mixtures including chloropicrin (as a solvent).	Very effective so produced in large quantities. Attacks all exposed parts of the body especially moist areas. Potent carcinogen.
BLOOD AGENTS (lethal action on oxygen transport)	Cyanogen chloride (CK) Hydrogen cyanide (AC)	AC is not effective alone and will only be present as mixtures with SnCl ₄ and AsCl ₃ . CK was used alone.
CHOKING AGENTS (cause lethal lung damage)	Carbonyl chloride (phosgene) (CG) Diphosgene	Used in large quantities as lethal, non-persistent agents.
LACRIMATORY AND IRRITANT SMOKES	Bromobenzylcyanide (BBC) Thickened or viscous BBC(BBCV) Ethylidoacetate (KSK) Chloropicrin (PS)	Irritants were used in large quantities. These early versions were quite toxic, especially PS which can be lethal in high concentrations.
DILUTENTS	Terachloromethane (carbon tetrachloride) Nitrobenzene Chlorobenzene Chloropicrin	Used in production or in mixtures to alter the physico-chemical properties e.g. freezing point.

See Appendix B for further details of chemicals.

Table 3.2 - Principal groupings of WWII CW agents

PRINCIPAL TYPES OF CW AGENTS	COMPONENT SUBSTANCES	COMMENTS
MUSTARD AGENTS	Sulphur mustard (H) HT mixture – sulphur mustard (H)/oxygen mustard (T) mixture with low freezing point.	HT was the principal UK CW agent during WWII and was produced, stockpiled (bulk and filled munitions) in large quantities.
VESICANT ARSENICAL AGENTS	Lewisite (L)	Produced in limited quantities (hundreds of tons) in UK but may have been imported by US forces in larger amounts.
BLOOD AGENTS	Cyanogen chloride (CK)	Produced and filled into aircraft bombs in limited quantities. Used much more extensively by US forces and may have been imported to UK.
CHOKING AGENTS	Carbonyl chloride (phosgene) (CG)	Principal UK lethal agent. Produced and weaponised in large quantities (thousands of tons).
LACHRYMATORY AND IRRITANT SMOKES	Bromobenzylcyanide (BBC) Chloracetophenone (CN or CAP)	Produced in large quantities and widely used in training. Also stockpiled for war.
DILUTENTS	Carbon tetrachloride Nitrobenzene Chlorobenzene	Trace amounts from production.

See Appendix B for further details of chemicals.

Table 3.3 - Principal groupings of live CW agents used for identification sets (sniff kits)

PRINCIPAL TYPES OF CW AGENTS	COMPONENT SUBSTANCES	COMMENTS
MUSTARD AGENTS	Sulphur mustard H	Typical garlic odour.
ARSENICAL AGENTS Vesicants Non Vesicants	Lewisite (L) Diphenylchloroarsine (DA) Diphenylcyanoarsine (DC) Adamsite (DM)	Typical geranium odour.
BLOOD AGENTS	Cyanogen chloride (CK) Hydrogen cyanide (AC)	Bitter almonds odour.
CHOKING AGENTS	Carbonyl chloride (phosgene) (CG) Chlorine (as Chloramine T)	New mown hay odour. Smell of bleach.
LACHRYMATORY AND IRRITANT SMOKES	Bromobenzylecyanide (BBC) Ethylidoacetate (KSK) Chloacetophenone (CN or CAP) Chloropicrin (PS)	Strongly irritant to the nose.
SIMULANTS (Visual) (These were produce to simulate the visual appearance of CW for training purposes)	Mustard H= Castor oil and tetrachloromethane (CCl ₄) BBC = Stockholm tar and CCl ₄ Lewisite L = castor oil and CCl ₄ DM = green coloured silica CAP = Phenol and ground glass CG = CCl ₄ KSK = Ethanol or bromine water PS = Nitrobenzine DC = 2,4-Dinitrobenzene DA = Potassium ferrocyanide	COSHH regulations may apply but the visual simulants used in some types of identification set were made to be harmless.

See Appendix B for further details of chemicals.

Table 3.4 - Principal groupings of CW agents used for R&D (not exhaustive, indicative only)

PRINCIPAL TYPES OF CW AGENTS	COMPONENT SUBSTANCES	COMMENTS
MUSTARD AGENTS	Sulphur mustard H HT mixture – sulphur / oxygen mustard mixture nitrogen mustards (HN1, HN2, HN3) Sesquimustard (Q) Also various mixtures and thickened or viscous forms.	Many mixtures were produced especially during WWI and between the wars. By WWII UK had standardised on HT thickened in some munitions.
ARSENICAL AGENTS	Lewisite (L) Diphenylchloroarsine (DA) Diphenylcyanoarsine (DC) Adamsite (DM) Methyldichloroarsine (MD) Ethyldichloroarsine (ED) Phenyldichloroarsine (PD)	Arsenical agents were developed by Germany during WWI since they could be disseminated as aerosols which penetrated the early respirators. Lewisite was developed in the US at the end of WWI as a vesicant.
BLOOD AGENTS	Cyanogen chloride (CK) Hydrogen cyanide (AC)	
URTICANT AGENTS (damaging, causing intense pain)	Phosgene oxime (CX)	R&D only.
CHOKING AGENTS	Carbonyl chloride (phosgene) (CG) Diphosgene	
INCAPACITANT AGENTS	3-Quinuclidinyl benzylate (BZ) D Lysergic acid diethylamide (LSD)	R&D only.
LACHRYMATORY AND IRRITANT SMOKES	Bromobenzylecyanide (BBC) Ethylidoacetate (KSK) O-Chlorobenzylidene malononitrile (CS) Chloacetophenone (CN or CAP) Chloropicrin (PS)	Widely distributed for training and as riot control agents. More recently CS used in some countries for personal protection.
NERVE AGENTS (German agents were not known in UK until after WWII).	Sarin (GB) Soman (GD) Tabun (GA) VX	Restricted to a few known sites. Unlikely to be encountered in large quantities with the possible exception of GA in German aircraft bombs. Minute amounts are lethal by blocking nerve function.
SIMULANTS	Methyl salicylate Dipropylene glycol monoethylether Diethylamine / ethanol	
DILUTENTS	Carbon tetrachloride Nitrobenzene Chlorobenzene	

See Appendix B for further details of chemicals.

Within the following sections additional descriptions are provided of each of the main categories of CW presented in the above tables.

3.2.2 Mustard agents or vesicants

Vesicants are agents which have the ability to cause blistering, in particular of the skin. These are much less lethal than nerve agents but are extremely toxic and effective at causing injury. There were in the order of 70 vesicant agents, many of them mixtures, which were known at the outbreak of WWII. Of these only a handful are known to have ever been weaponised. Mustard, in a range of forms (see below), is the main vesicant CW which is likely to be encountered.

Sulphur Mustard (H)

Mustard (sometimes referred to as mustard gas) is one of the earliest CW agents.

Mustard was first synthesised in 1822, and it was first used as a CW agent at the end of WWI. Although it was one of the earliest CW agents, it remained in use as a chemical weapon because it is so effective and is relatively simple to manufacture.

Sulphur mustard (bis-chloroethyl sulphide) is the traditional form of Mustard used during WWI usually given the code letter H. Analogues of sulphur mustard were developed following WWI, notably oxygen mustard (2.2 bis (2 chloroethylthio) diethylether), code letter T. This substance is similar in nature to H, although it is a slightly more potent blister agent, is less volatile and is more persistent in soils. Mixtures (40:60) of H and T (known as HT) were used almost exclusively by the UK during WWII because the mixture has a lower freezing point and, unlike H, remains liquid at winter temperatures. Weapons grade Mustard mixtures of HT were produced directly using the Levenstein process and crude product was used without purification. HT therefore contains impurities such as sesquimustard (bis (2 chloroethylthio) ethane), code letter Q.

Sulphur mustard, along with the other Mustard compounds, is a vesicant leading to severe blistering of the skin, especially in moist areas of the body. Mustard belongs to the class of substances referred to as "blister agents" since the wounds resemble large blisters which are slow to heal because of damage to cellular DNA. In addition to its blistering properties, it causes lung damage if inhaled and can lead to severe eye damage. Mustard agents have also been found to be potent carcinogens and, as such, exposure should be eliminated by the use of engineering controls and PPE. The toxic effects of Mustard agents are well documented. Information relating the effects of sulphur and other types of Mustard can be found on-line in material safety data sheets produced by the US army, from the Organisation for the Prohibition of Chemical Weapons (OPCW) and at the Mitretek Systems web site. (See Section 9 for further details of these and other web sites.) Information can also be obtained in the UK direct from DERA Porton Down.

Nitrogen Mustard (HN1, HN2 and NN3)

During the 1930s other variations of Mustard were developed. The nitrogen mustards were developed in Germany and had effects similar to those of sulphur mustard. They were not weaponised in this country so are most unlikely to be found on any site other than Porton Down.

Lewisite

Although it contains arsenic, Lewisite is a vesicant so is included here. It is lethal by the inhalation route and acts as an incapacitant by dermal contact. Exposure to vapour results in the rapid onset of irritation to the eyes and respiratory tract. Exposure to liquid causes immediate pain to the eyes and skin, blistering occurs within a few hours. Exposure also leads to damage to the eyes and lungs. It is also a systemic poison. Healing of the blisters formed occurs more rapidly than for those caused by Mustard. Although the necessary research has not been done, lewisite is probably also a carcinogen as are other arsenic containing compounds. In addition to the effects of Lewisite itself, the initial breakdown products from the hydrolysis of Lewisite (Cl-CH=CH-As(OH)_2 and Cl-CH=CH-As=O) are also toxic and have vesicant properties. Further details of the toxicity of Lewisite can be found on numerous European and US web sites, including the US Army Chemical and Biological Defense Command, Mitretek Systems and OPCW.

3.2.3 Arsenicals

Arsenical compounds were first used during WWI by the French and Germans as sternutators or vomiting agents.

Clark I (DA)

This is an incapacitant by the inhalation route. Clark I causes irritation to the eyes, nose and throat, together with other symptoms which include severe headaches, chest pain, nausea and vomiting. At high concentrations exposure can lead to lesions of the skin and lungs.

Clark II (DC)

As with Clark I, Clark II is an incapacitant via the inhalation route. Exposure results in irritation of the eyes and nose, followed by coughing, sneezing, severe headache, acute chest pain, nausea and vomiting. Less harmful than Lewisite and Clark I.

Adamsite (DM)

Incapacitant via the inhalation route, exposure results in irritation of the eyes, nose and throat, symptoms progress to coughing, sneezing, severe headaches, acute pain and tightness in the chest, nausea and vomiting.

3.2.4 Blood agents

Hydrogen Cyanide (AC)

Hydrogen cyanide (AC) is the earliest known blood agent (so called because it interferes with oxygen transport in the blood) used in CW. It was used extensively by the French during WWI, usually in mixtures with SnCl_4 and AsCl_3 in an attempt to increase the vapour density (which for hydrogen cyanide is less than air) and prevent loss of contact with the ground.

Hydrogen cyanide is lethal by inhalation, and can also be taken up via the skin (cutaneous). It acts by inhibiting metal-containing enzymes such as cytochrome oxidase (containing iron). Inhibition of this enzyme leads to interference with cell respiration. Symptoms of poisoning vary according to the route of exposure. Inhalation results in symptoms such as restlessness and increased respiratory rate, also giddiness, headaches, weakness, and difficulties with breathing. Higher doses can lead to convulsions, respiratory paralysis and unconsciousness. At high concentrations early warning symptoms such as those described above are not seen and those exposed appear simply to collapse and die.

Cyanogen Chloride (CK)

Unlike AC, CK is a heavy gas which is also rapidly lethal via inhalation. Exposure results in immediate, intense irritation of the eyes, nose and throat and breathing difficulties, progressing to unconsciousness and death.

3.2.5 Urticant agents

The only urticant (pain producing) agent that is known or has ever been seriously considered for use as a CW is phosgene oxime (CX). It has been produced for R&D purposes only and is not likely to be encountered in the UK at any site other than Porton Down.

3.2.6 Choking agents

Carbonyl Chloride (phosgene)(CG)

Phosgene is lethal via the inhalation route. Symptoms begin with irritation of the eyes, nose, throat and respiratory tract, progressing to nausea and vomiting followed by massive pulmonary oedema leading to death.

Phosgene was used in WWI and WWII and was one of the first "war gases" to be used. This substance can be extremely hazardous if encountered in intact munitions. It is a heavy gas and when released can travel and have harmful effects for long distances (e.g. up to 20km) downwind. As with all intact munitions, those containing phosgene should be treated with extreme caution. In addition to the risk from toxic compounds which may be present, it will not be known whether they still have explosives and fuses attached to them and they could potentially explode.

In contact with air and water CG breaks down rapidly to produce harmless compounds and consequently has low persistence.

3.2.7 Incapacitant or lachrymatory agents

Lachrymatory agents (commonly referred to as tear agents or tear gases) are now generally used for riot control and military exercises, but have also been weaponised and used as CW agents in the past. Although incapacitants have been used since ancient times in wars, the first tear gas known to be used in modern warfare was chloropicrin, which was used in WWI. Other substances were developed during and after WWII, notably:

Ethyl iodoacetate (KSK);
Bromobenzylcyanide (BBC);
Chloroacetaphenone (CN or CAP);
O-chlorobenzylidene malonitrile (CS).

All tear gases cause almost instant pain in the eyes, tears and cramp in the eyelids. In addition to the lachrymatory effects, exposure also results in irritation of the nose, throat, mouth and respiratory tract and in some cases the skin. Most of the tear gases are simply incapacitating i.e. non-lethal, with symptoms continuing as long as the concentrations remain fairly high. The symptoms stop fairly soon after the exposure ceases. Sensitivity to tear gases varies considerably between individuals.

Bromobenzyl Cyanide (BBC)

BBC is a tear gas which acts as an incapacitant via the inhalation route. Exposure results in severe eye and nose irritation, acute forehead pain and a burning sensation in the mucous membranes.

Ethyl Iodoacetate (KSK)

KSK is harmful via inhalation and cutaneous routes of exposure. Exposure results in irritation of the eyes and throat. Symptoms therefore include lachrymation and coughing and in some cases severe conjunctivitis and lung oedema.

O-Chlorobenzylidene Malonitrile (CS)

Incapacitating via inhalation and cutaneous routes. CS is an extremely effective irritant to the eyes, nose and throat causing immediate lachrymation. High concentrations result in nausea and vomiting.

Chloropicrin (PS)

Chloropicrin is an incapacitant via the inhalation route, and was used as a tear gas from WWI onwards, although it has also been used in association with Mustard. Exposure results in eye, nose and throat irritation, nausea, vomiting and skin lesions.

3.2.8 Nerve agents

These are considered to be the most lethal of all the chemical warfare agents and were only investigated in the UK following the discovery after WWII that Tabun (GA) had been developed by Germany. Although all were produced in research quantities (a few grams) in the UK, a few (Sarin (GB) and VX) were produced in R&D (tens of kilograms) quantities. When the UK decided to abandon its offensive CW capabilities in the 1950s, all stocks other than those required for defensive research purposes were destroyed. Production and storage of such agents is now regulated under the terms of the CWC. Nerve agents are unlikely to be found as contaminants in significant quantities and were only produced and used on a limited number of sites. However, a large number of bombs filled with GA were brought to the UK after WWII and stored at a number of RAF sites for some years before being sea dumped. It is known that emergency procedures were developed to bury leaking munitions and there remains a remote possibility that such an item will eventually be found.

All nerve agents are organo-phosphorus (OP) compounds which are related to OP pesticides. They are all extremely toxic and are lethal via inhalation and cutaneous routes. They can also lead to poisoning if they are used to contaminate food or liquids. They act by affecting the transmission of impulses in the nervous system and can lead to a wide range of toxic effects dependent on the agent, the route of administration, the dose to which the individual is exposed and the time of exposure. For example, inhalation is the most critical route, as the agent can be absorbed directly from the lungs and diffuse rapidly into the blood supply. Symptoms of inhalation at low doses include salivation, tightness of the chest, runny nose, tiredness, headaches, slurred speech and problems with vision such as the inability to focus. These progress to difficulty in breathing and coughing. High doses lead to lack of control over muscles leading to a loss of normal bodily functions. Eventually muscular paralysis affects the respiratory muscles as well as respiratory centres of the central nervous system (CNS) leading to death by suffocation.

The toxicity of the nerve agents is very well documented and can be found in alternative toxicology textbooks, especially those relating to OP pesticides (Marrs 1996). Other specific sources of information relating to toxicity include Kirk Othmer Encyclopedia of Chemical Technology 4th edition, Volume 5 (1993). On-line sources of information (web sites) are detailed in Section 9. Further information is available from DERA Porton Down.

Tabun (GA)

This is the oldest known of the nerve agents, and the least toxic of the four main substances discussed here. A material safety data sheet (MSDS) has been produced by the US Army for Tabun, which provides detailed information relating to its toxicity.

Sarin (GB)

More toxic than Tabun, of equal toxicity to Soman, but less toxic than the "V" agents (e.g. VX see below). Detailed information relating to the toxicity of Sarin can be found on-line in the form of a MSDS, at the US Army Chemical and Biological Defense Command.

Soman (GD)

It is of equal toxicity to Sarin and is lethal by inhalation but can also be taken up via the cutaneous route.

VX and other V agents

Highly persistent, and said to be ten times more toxic than Sarin or Soman. Uptake is mainly through the skin, since VX is the least volatile of the nerve agents and as such is less likely to be present as a vapour. If VX is present as an aerosol, it could also be inhaled.

3.3 Physical Characteristics of CW Munitions

Intact CW munitions from both world wars are recovered regularly throughout the UK from old firing ranges, storage areas and production sites. Burials of CW munitions continue to be discovered on a regular basis. The numbers recovered per year vary but are consistently between 500–1,000 rounds per year. Items recovered include mortar bombs, artillery projectiles, vivens projectors, ground bombs, aircraft bombs and spray tanks.

When recovered from the ground all of these items are rusty and difficult to differentiate from conventional explosive munitions even by experts. Some types do not look like munitions at all and resemble tin cans and car exhausts – these types are thin walled and fragile and most likely to leak. Fired munitions from proofing ranges are the most hazardous items and have the potential to explode when disturbed. Many munitions were buried because they were leaking or developed leaks during recovery. All such items are extremely hazardous to site workers and the public and, if found, should not be touched, the hole should be back-filled with earth if possible, and the find reported to the police.

A selection of photographs showing some examples of recovered CW munitions is given at the end of this section. **This is intended only to illustrate a few of the possible CW munitions which may be encountered and is NOT intended in any way to be a comprehensive record of all types of CW munition.**

3.4 Raw Materials

Many of the raw materials or precursors produced during the manufacture of CW agents are toxic and hazardous, some of them may be carcinogenic/mutagenic. In addition to these, a number of harmful solvents are associated with CW agents as they were used either as dilutents or in the manufacturing process. These substances may be present in soils, particularly in areas near to where the raw materials were stored, e.g. laboratories and

production facilities. It is therefore important to consider them in the analytical suite and to assess them along with the CW agents themselves during any risk assessment.

Some of the more important raw materials used for the production of CW agents are detailed in Table B.3 in Appendix B.

3.5 Breakdown Products and Factors Affecting Degradation

3.5.1 Breakdown products

The substances listed in Table B.2 in Appendix B have not been produced in the UK for many years. As such, if CW agents were present in soils, they are likely to have undergone a certain amount of decomposition. Except for Mustard, CW agents in their original form are unlikely to be found unless they are within a shell or other form of device which has not leaked.

Table B.4 in Appendix B provides a list of the known breakdown products of the CW agents previously discussed. The reader should be aware that this is not a definitive list, and new breakdown products are still being discovered.

The breakdown products will also vary depending on how the material was originally disposed. Historical disposal techniques such as open burning or decontamination using bleach may have led to the formation of dioxins as well as a range of other compounds formed from reactions with CW agents. Table B.5 in Appendix B also gives examples of such reactions and the compounds which may be formed as a result.

Mustard

Intact Mustard persists in the soil for many years. It is toxic to micro-organisms so is not biodegraded in the same way as most organic compounds. Mustard also has a very low solubility in water and tends to form an outer crust of insoluble polymerised decomposition products that further slows the rate of solution. Consequently, although once in aqueous solution the hydrolysis of Mustard proceeds rapidly, the overall process takes place very slowly. Unfortunately, Mustard was produced in very large quantities during WWII and widely distributed to sites throughout the UK so its occurrence is potentially widespread.

Arsenicals

In a similar way to Mustard, the arsenical CW agents are toxic to micro-organisms and tend not to be degraded by them. However, unlike Mustard, the products of the chemical degradation processes remain toxic due to the arsenic content. Fortunately, arsenical CW agents were not widely used in the UK. The main one produced during WWII was lewisite which hydrolyses readily in the environment. Lewisite was restricted to a limited number of RAF sites and most, if not all, was destroyed by open pit burning at sites which remain heavily contaminated with arsenic residues to this day. Lewisite was more widely used by US

forces stationed in the UK although it is not known what quantities were originally present or were destroyed at US bases.

Nerve Agents

Nerve agents, when released to the water environment, are generally hydrolysed quickly to less toxic materials in solution. However, some of the hydrolysis products still contain a modicum of nerve agent activity.

Other CW Agents

As can be seen from the information presented in Table B.2 (in Appendix B), the persistence of many of the other CW agents used is variable and whilst many are relatively persistent others are of low persistence. For example phosgene is volatile and, as a result, is unlikely to persist in the environment unless it has been stored carefully or is present in intact munitions which have not leaked.

3.5.2 Factors Affecting Degradation

The degree and rate of degradation will also depend on a range of site specific conditions such as:

- amount of contamination;
- microbial content of soil;
- soil type (presence of metal ions, etc);
- soil moisture content;
- soil temperature;
- organic matter;
- oxygen content/redox potential;
- pH;
- depth of burial.

These factors can also influence the degradation route and hence the type of degradation compounds that will be found, as with the environmental degradation of any organic chemical.

Toxicological data are available for many of the raw materials used in the manufacture of CW agents, as many of the compounds could be encountered on other sites. Toxicological data for these substances can be obtained from conventional sources such as the Department of the Environment, Transport and the Regions (DETR), World Health Organisation (WHO) and the US Environmental Protection Agency (US EPA). (See Section 9 for additional details.)

For the more unusual raw materials and precursors, the CW agents themselves and the more commonly encountered breakdown products, toxicological data are less easy to obtain. In most cases, the conventional sources will not have data for these substances and specialist assistance will be required. However, research is ongoing and in many cases the data does not yet exist.

A number of international and US organisations have material safety data sheets and other similar reports which provide information on the toxic effects and other physico-chemical data for the principal CW agents. See Section 9 for details of organisations and web sites where this type of information including information on decomposition and breakdown products can be found.

Specialist assistance will be necessary for the detection, safe handling, analysis and assessment of any site at which CW agents are suspected of being present. There are a limited number of laboratories world wide with suitable experience of handling these substances (DERA Porton Down is the only site in the UK). Such organisations will be able to provide toxicological data for the majority of the substances encountered. However, not all of the breakdown products of these substances have been identified and work on identifying them and developing suitable toxicological data in order that they can be assessed is ongoing.

Plates 1 - 4 Smelling Sets



Plate 1



Plate 2



Plate 3



Plate 4

Plates 5 - 7 Views of Suspect Chemical Munitions



Plate 5



Plate 6



Plate 7

4. SITE CHARACTERISATION

KEY QUESTIONS ANSWERED IN THIS SECTION

1. Which information sources should be used for the desk study?
2. How should the investigation be approached?
3. What are the main differences from a conventional contaminated land investigation?
4. Are special sampling and sample handling procedures required?
5. 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 which is suspected of being contaminated with CW agents. The overall procedures involved in characterising CW contaminated sites have many aspects which are common to other types of contaminated land site. Consequently any such generic guidance is explicitly excluded from the scope of this section which relates solely to the particular issues which are exclusive to CW 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 CW agents may be encountered:

- lack of information is likely to be a major barrier to obtaining details of the activities carried out and the contaminants which may be encountered;
- as with other MoD sites, lack of information does not mean that CW agents are not present. The virtual impossibility of proving the negative is recognised, but investigators will need to examine all available evidence most carefully before ruling out the possibility of the presence of CW material. **The wisest course of action is to be aware of the potential of CW on all current/former MoD sites;**
- knowing where to look for the relevant information, and how to interpret the information which is available are important considerations, and as with other MoD sites, this will often mean that specialist assistance must be sought, from organisations familiar with MoD land;
- in some cases, the information necessary for the desk study may still be classified. However, it is unlikely that information relating to the wartime use and storage of CW-

related materials will still remain classified and therefore access can normally be obtained. If information concerning a particular site remains classified there is likely to be a specific reason for this;

- CW sites are often likely to be located away from the main areas of activity because of the nature of the materials handled. This is certainly the case with major test ranges and production facilities. However, improvised storage was used extensively during WWII. Although these storage areas were often located at military sites, this was not always the case and industrial sites located much closer to built-up areas were also used.

4.2.2 Operational time periods

The period of site operation is an important factor in determining which CW agents may be encountered.

The development of chemical warfare agents in the UK began in earnest during 1916, in response to use of chlorine gas by the German Army at Ypres in 1915 (see Section 2.3.2 on CW production sites for further details). From 1916 until the end of WWI, a vast range of materials, both known to industrial chemists and newly synthesised was assessed as potential CW agents.

DERA Porton Down consider that hundreds of compounds would have been synthesised in laboratories, of which up to a hundred may have progressed to live field trials in the UK, possibly involving weaponisation to some degree. Of these several tens of compounds were produced in sufficient quantities for operational use. However, by the end of the war the number of effective CW agents had been reduced to a handful.

Between the wars, and in the light of several treaties, further research into new CW agents was minimal, and focused on the effective dispersion/release of a small number of CW agents. When the UK started to stockpile CW agent munitions prior to WWII, only the following agents were being produced in any significant quantities:

- Mustard; and
- phosgene.

Tables 3.1 and 3.2 in Section 3 provide details of the principal CW agents used in the main periods of CW production in the UK - WWI and WWII.

4.2.3 Common mistakes

The main errors in assessing former CW sites are:

- the failure to understand the multitude and variety of processes and protocols which were followed by servicemen (particularly during WWII) in respect to the handling, storage and disposal of CW;

- a failure to appreciate that only a very small proportion of the required data are available or easily accessible with which to perform a desk study;
- the dismissal as unrealistic of situations which would not happen today, but may have happened in the past, particularly during war time such as the on-site burial of CW munitions;
- an underestimation of the hazards associated with CW contaminated sites;
- misunderstanding of the levels of protection required for (a) workers and, (b) the public and the inadvertent exposure of workers to hazardous chemicals and carcinogens including toxic breakdown products;
- dealing with the explosive ordnance disposal (EOD) operation in isolation and without due consideration to the environmental issues associated with excavating highly contaminated soil;
- inappropriate involvement of non-specialist consultants who do not necessarily have an adequate understanding of the safety and political issues associated with CW agents;
- inappropriate involvement of non-specialist analytical laboratories who may not have access to the correct analytical procedures or authentic standards of CW agents.

Many of the records dating from WWII were destroyed or lost after the war, mainly as a result of a lack of space and appropriate storage facilities. In addition, many of the methods (for processes such as leaking munition disposal) adopted at military sites were not fully documented anyway, rather being established techniques demonstrated by senior officers to junior ranks as and when they were required to perform certain duties. Often the only source of data is anecdotal from personnel who were invariably junior at the time and therefore not likely to have been fully aware of all activities at a site. This information is invariably hard to obtain, often of dubious merit, and more likely to allude to the possible presence of CW than confirm the absence.

4.2.4 Desk study check-list for CW contaminated sites

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

<p>Have all of the following specialist information sources been approached?</p> <ul style="list-style-type: none">• Demilitarisation, DERA Porton Down, Salisbury, Wilts;• Armed Services Historical Branches;• Public Records Office;• Defence Estates;• Royal Air Force CSSB.
<p>Has the operational period of the site been established?</p>
<p>Were any of the following features present on the site:</p> <ul style="list-style-type: none">• Laboratories;• Production – mixing, filling, decanting areas;• Proofing ranges/general firing ranges;• Storage areas;• Drainage systems;• Ponds, wells;• Waste disposal sites;• Waste burning grounds. <p>If yes to any of the above have they been located on the site?</p>
<p>Are unexploded munitions, either CW or conventional likely to be present?</p>
<p>Has the site been cleared of unexploded munitions? And if so to what level?</p>
<p>Are the processes and procedures which were undertaken on the site properly understood?</p>
<p>Is there any information which indicates that CW should NOT be expected to be present?</p>
<p>Are CW decomposition products or precursors/raw materials likely to be present?</p>
<p>Should other types of contaminants be considered apart from CW?</p>
<p>Has specialist advice been obtained to assist with the desk study?</p>

4.3 Site Inspection and Investigation

This section of the report provides some general guidance on the issues which should be considered when planning and undertaking the investigation of CW contaminated sites. However it is not intended in any way to be a detailed guide to the investigation of such sites.

Both the inspection and investigation of suspect CW contaminated sites are highly specialised activities compared with equivalent activities on 'conventional' contaminated land sites. As such, this work should be undertaken only by organisations that can demonstrate both an extensive track record in this area and which can supply the full range of expertise required.

Reference should also be made to Environment Agency R&D Technical Report P5-042/TR/01 and R&D Technical Report P5-042/TR/02.

4.3.1 Site inspection

Given the dangers associated with live ordnance, and the possible implications of the detonation of a conventional or CW munition, personnel who are not trained Explosive Ordnance Disposal (EOD) officers should not enter a site where live ordnance has been found until an appropriate ordnance clearance certificate has been provided.

The site inspection visits should always be based on the maximum amount of available information that can be obtained from the desk study phase. Although this is also the case with other types of contaminated land, it is particularly important for possible CW contaminated sites owing to the explicit acute hazards that may be present. Site staff will need to be equipped with the relevant level of PPE and trained accordingly (see Section 7 for health and safety aspects). At operational MoD sites, access may be restricted to individuals with appropriate security clearance and specific procedures may need to be followed, both generally and when carrying out intrusive works. There may also be constraints placed on site inspections (as well as investigative or remedial works) due to military operational considerations.

4.3.2 Site investigation

Approach to Site Investigations

An appropriately qualified Ammunition Technical Officer (ATO) should be present at all times during any intrusive investigations where there is the remotest likelihood of old ordnance being found on the site. The decision on whether or not to clear a site of ordnance first, or to have EOD or ATO-trained personnel on site during intrusive work, should be based on information gathered from the desk study in conjunction with discussions with appropriately trained specialist personnel. This decision should be based on a clear understanding of the complexities of the individual site and a full understanding of the consequences of intrusive intervention. For example, the conventional approach to EOD clearance of a heavily contaminated burial pit could create a pathway for contamination to enter a water course where none previously existed.

The major difference between the investigation of possible CW contaminated sites and conventional contaminated land investigations is the need to determine:

- the presence of any buried objects which could be live ordnance (CW or conventional) or CW containers. These sources will often be small in area, and numerous, for example at a firing range, and hence difficult to locate comprehensively;
- the presence of any large volumes of uncontained CW which remain buried in the ground.

If there is any evidence to suggest the presence of buried munitions, storage containers or burial pits on site, a conventional approach to site investigation should not be attempted due to the very significant safety implications involved. Bulk CW agent is a significant hazard, and can only realistically be dealt with by personnel in appropriate PPE and with the correct specialist training.

The first concern is the explosive hazard associated with munitions which could still produce effective CW agent dispersion and gross contamination of personnel and equipment in addition to the initial explosive damage. Munitions with explosive charges intact are regularly retrieved from a variety of sites. The risk of an explosion during recovery and transportation is low but depends on the fuse, type of explosive burster used and other factors.

It is beyond the scope of this document to give guidance on the explosive safety of buried CW munitions but some general points can be made. In general, handling risks are greatest with fired munitions or “blinds” where the fuse safety interlocks have been disrupted and it has failed to function but remains susceptible to impact or vibration. Corrosion can also make fuses unsafe. Chemical reactions with picric acid and metals can make this type of high explosive (HE) burster more shock sensitive than TNT fills and considerably more sensitive than low explosive gunpowder charges. **Any munition find must immediately be reported to the Police who will seek appropriate expert advice.**

The second concern is the explicit chemical hazard associated with a large volume of CW agent in a fragile, corroded storage container or contained in some form of pit. Some munitions, particularly mortars or aircraft bombs were very thin walled, and as such may have corroded significantly since burial. Given the persistent nature of some CW agents (for details see Section 3.5) it is possible that under specific conditions considerable quantities of CW agents such as Mustard may still be active even after the container has corroded away.

It is not appropriate to give details within this document of investigation procedures for sites containing explosively configured CW munitions or gross CW contamination. This is a highly specialist and potentially extremely dangerous activity. If either of these situations is suspected at any stage of the site characterisation process, the first step is to inform the Police, who will call out the appropriate EOD team. If, as should be the case, the desk study produces this information, an appropriately trained team can be called in either to perform an initial ‘sweep’ of the area, or to work in consultation with the site investigation team depending on the nature and scale of the suspected CW hazard.

Alternatively if there is specific evidence to suggest neither of these cases is likely, then a site investigation can proceed following relatively conventional methods. Low levels of CW breakdown products are likely to present a significantly lower hazard than other more conventional contaminants such as dioxins, and other chlorinated organics or certain inorganic particulate matter. Nevertheless, where Mustard was destroyed in the past by open pit burning there is a significant risk that quantities of intact CW agent will remain and present a significant hazard to workers during intrusive operations including sampling.

In summary, unless there is an appropriate degree of assurance that CW is not present, either explosively configured or not, a site clearance by appropriate CW-trained personnel is recommended. If the appropriate information is available then, in principle, a relatively conventional site survey can be conducted. In this event all personnel should be made aware of the possibility that CW-related finds may be made, and a protocol to address this situation should be developed, read and understood by all personnel working on site. In the event that there is any doubt with respect to the CW status of the site, then specialist site clearance should always be undertaken in advance of any other site activities.

Screening Techniques

Table 4.1 identifies some types of equipment suitable for safety and contamination screening for CW agents. Some of the hand held monitors (CAM and detector paper) have been produced for military use whereas others (PID and Draeger) are in general use. The only method available for detecting low volatility liquids at low temperatures (such as the T component of the Mustard agent mixture HT) is detector paper. All the other methods use vapour detectors and rely on at least some of the contaminant evaporating. At low temperatures, and for contaminants adsorbed onto soil particles, these methods are not reliable and at best can give qualitative information only. Nevertheless, if used with caution, this type of equipment can give a rapid indication of the presence and location of contamination 'hot spots' and has great value in allowing workers to identify and thereby avoid contact with CW hazards.

Much more effective, semi-quantitative screening can be achieved by vapour sampling onto adsorbant containing tubes followed by thermal desorption and analysis by a technique such as GCMS. Effectiveness can be enhanced by putting samples of suspected contaminated soil in polythene bags, warming and sampling the headspace. Such screening can be carried out rapidly on site using suitable equipment in a mobile laboratory.

Sampling Techniques

The use of percussive samplers such as shell and auger borehole rigs and window samplers should be avoided on sites where buried ordnance or CW containers are suspected to be present. Where low levels of CW or CW breakdown products are known to be present conventional sampling techniques for other types of contaminated sites can be employed.

All samples should be packaged in appropriate containers. A container's suitability is very much dependent on a whole host of different factors, including the method of transport, the quantities involved and the sample itself. All containers are required to be approved by the UN, be suitably labelled and meet all the transport regulations applicable (CAA, IATA, Dangerous air cargo etc.). Once packaged, the samples should then be put in a secondary containment system which protects the samples during transfer to the laboratory and would contain any spillages/breakages. Secondary containment generally involves packing in sealed compartments with integral activated carbon or Fuller's Earth to adsorb any leaked CW agents. Ideally samples would also be cooled to reduce any vapour hazard associated with the contained sample. Samples should be packed by qualified personnel wearing the appropriate level of PPE so that there will be no release during transport, cross contamination of samples or contamination of analytical staff unpacking the samples.

The samples should be clearly labelled as potentially hazardous and suitable comments should be included on the chain of custody documentation to ensure that the receiving laboratory is informed of the potential hazards in advance of unpacking the samples.

4.3.3 Summary of potential pollutant sources and investigation techniques

Table 4.1 provides a summary of the main potential pollutant linkages which may be associated with CW contaminated sites. For each of the potential linkages it also lists the general type of investigation technique which is likely to be appropriate to provide additional information and which will enable a more detailed assessment of the potential linkages to be undertaken.

Table 4.1 - Summary of suitable investigation techniques and constraints

PRINCIPAL POTENTIAL POLLUTANT SOURCE	MAIN INVESTIGATION/ DETECTION TECHNIQUES	APPLICABILITY/ CONSTRAINTS
CW contaminated soils	<ol style="list-style-type: none"> 1. CAM (Chemical Agent Monitor) and CAM+ 2. Draeger 3. Detector Papers 4. PID 5. Odour and visual inspection from experienced personnel 6. Sampling and analysis 	<ol style="list-style-type: none"> 1. H, NA only but indicates other volatiles. CAM+ also sees CG and AC 2. All volatile organics 3. Broad range organics 4. Volatile Organics 5. Inherent danger from materials 6. Confirmation and trace analysis
CW contaminated buildings	<ol style="list-style-type: none"> 1. Swabs 2. Sample cores 3. Techniques as above 	Off-site analysis may be slow Mobile lab on-site for rapid screening

Chemical Analysis

There are no default analytical methods registered for CW agents equivalent to the NIOSH or EPA SW846 methods for environmental contaminants in the USA. Whilst this continues to be the case, UKAS or equivalent accreditation for a full CW screen will continue to be the only benchmark which can provide evidence of appropriate analytical quality. Only those laboratories which hold an accreditation covering both the preparation and analysis of CW contaminated soils and waters should be used for the analysis of CW.

The following analytical sequence should be followed for samples which are suspected of containing CW:

- the sample should be assessed visually for explosive components (a slurry of explosive content lower than approximately 20% is not explosive). This should be performed by an appropriately trained explosive specialist, ideally an ATO;
- the sample should then be screened for radiological contamination using a device such as a Geiger meter;
- the sample should then be split, and half irradiated to remove any potential biological contamination;
- the irradiated sample can then be analysed for CW contamination and once confirmed free from visually explicit CW, a screen for trace explosives can be performed if required;

- the non-irradiated sample can be analysed for microbiological content (if required) once the other half of the sample has been shown to be free from gross CW contamination.

This logical progression of analyses allows individual disciplines to conduct analysis on samples using their own protocols without modification or fear of personnel becoming injured or exposed to some other form of contamination. Whilst the process is extremely involved, and hence more expensive than conventional analysis of contaminated soil samples, it is likely that a good desk study will identify the necessary steps required in the analytical sequence.

Few commercial analytical laboratories are licensed to hold stocks of CW materials, including analytical standards, or to have the appropriate safe handling protocols for samples. However, some are still prepared to perform 'CW screens' on the basis of a general volatile organic material screen using gas chromatography with mass spectral detection. As with any analysis, a negative result is only validated by confirmation that a positive could have been seen if it was present. It is not possible to do this with sufficient confidence unless an analytical standard is available. Therefore, any laboratory chosen to perform a CW screen must hold analytical samples of all CW agents required to be screened for.

Laboratories which are not prepared to hold samples of CW analytical standards on the grounds of health and safety to personnel would be ill-advised to attempt analysis of environmental samples which could, in principle, contain significant quantities of hazardous material. Such laboratories are also likely to be ill-equipped to dispose of any CW contaminated samples safely and within the requirements of the CWC. Consequently this category of laboratory should not be used for the analysis of CW.

5. SITE EVALUATION

KEY QUESTIONS ANSWERED IN THIS SECTION

1. What are the primary pollutant linkages which should be assessed?
2. Which 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?

5.1 Scope

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

5.2 Pollutant Linkages

5.2.1 Human health

Direct human health related risks are the basis of the most important pollutant linkages associated with CW sites. These are likely to be dominated by acute effects due to direct contact and inhalation although exposure to some CW agents can also result in chronic health effects. The potential for harm to occur following explosion (both direct injury from the blast and secondary effects due to damaged buildings) is also of primary importance.

Specific considerations include:

- high acute toxicity of many CW agents;
- proven carcinogenicity of some CW materials;
- possible mutagenic/teratogenic effects of some CW materials;
- possible explosive hazards.

Within the pollutant linkage framework the following general considerations will apply when assessing CW sites:

- difficulties can be encountered in providing definitive characterisation of contamination sources;
- owing to the diversity of environmental behaviour exhibited by CW agents and the wide range of environmental settings, a wide range of exposure pathways can potentially be present, involving single or multi-media transfers. The latter is especially relevant, since attenuation of CW agents in the environment to non-hazardous levels may be extremely difficult;
- the principal issue with respect to CW sites is undoubtedly the potential direct effect on human health.

The assessment of CW sites should include consideration of the following uncertainties:

- contamination sources may not be completely known as historical information may be unavailable or incomplete;
- sources will often be small in area, and numerous, for example at a firing range, and hence difficult to locate comprehensively;
- CW agents may have sparse toxicological and physicochemical data, especially relating to chronic toxicity, requiring more assumptions to be made than with other types of contaminants.

5.2.2 Water environment

Risks to the water environment can be important in some circumstances, dependent on site hydrology and hydrogeology, and may constitute additional pollutant linkages at some CW sites.

Key considerations include:

- certain CW agents are soluble in water and therefore subject to the same migration potential as conventional contaminants;
- many CW agents are hydrolysed in aqueous solution to materials which are far more water-soluble. Some of these materials are considered non-toxic, some toxic in sufficient concentrations and others still retain their CW properties to a degree (see Table B4.1 in Appendix B). For example, Thiodiglycol (TDG) is the major hydrolysis product of Mustard and is far more water soluble than the parent CW compound;
- gross petroleum product and solvent contamination may result in free product (LNAPL/DNAPL) in which hydrophobic CW agents will be able to migrate preferentially.

5.2.3 Ecological systems

Pollutant linkages relating to harm to flora and fauna could be an issue at CW sites as these installations are often located in open and remote areas (e.g. Army ranges, training areas) and adjacent to fresh water/marine water bodies. Also, the large size of many MoD sites raises the possibility that several different habitat types could fall within the boundaries of the land.

Key considerations include:

- the potential for CW sites to be located near to (or even to include within their boundaries) sensitive ecological sites such as SSSIs (Sites of Special Scientific Interest);
- release of bioaccumulative CW agents, especially where this occurs directly into surface waters and direct to the ground surface;
- nerve agents are related to organophosphate pesticides and can exert highly toxic effects on animal life (note earlier comments relating to the limited production of nerve agents in the UK for R&D purposes).

General guidance and information on performing ecological risk estimation can be obtained from DERA Porton Down.

5.2.4 Buildings

Building materials and services are likely to be at greatest risk from damage associated with explosion of explosive charges associated with CW munitions. Certain CW agents are also corrosive to some building materials and others have the potential to migrate through plastic pipes. On hydrolysis some agents release acidic or corrosive gases. The highly hydrophobic nature of some CW agents has been suggested as an explanation for their absorption into certain materials, reducing the effectiveness of decontamination procedures and allowing the CW agent to seep out of materials at slower rates over prolonged time periods.

5.3 Assessment of Investigation Data

Most available data concern Mustard and phosgene as these are the main CW agents found in the UK. Additional toxicology work has been performed with nerve agents, owing to their extreme toxicity.

5.3.1 ‘Trigger/Guideline values’

There are no published ‘trigger/guideline values’ for CW agents in either soils or groundwater/surface water in the UK.

5.3.2 Mustard and Thiodiglycol TDG

Thiodiglycol (TDG) is the major hydrolysis product of Mustard and is far more water soluble. TDG concentrations above approximately 50 mg/kg are usually a strong indication of the presence of a source of an uncontained CW Mustard agent on site. Elevated concentrations of TDG are frequently encountered some distance from the site of Mustard contamination. The presence of elevated concentrations of TDG and the absence of Mustard should not be interpreted to suggest that all Mustard has been hydrolysed and the hence that site is relatively safe. Rather this situation is likely to mean that a source of Mustard is still present elsewhere within the site that has not been identified by the investigation.

The characteristics of Mustard in soil are such that the parent CW agent is found as discrete globules, rather than a dilute dispersion through the soil. This point stresses the importance of effective sampling, as potentially high concentrations of Mustard may not be seen if a poor or insufficient sampling plan is followed.

5.3.3 Nerve agents

Nerve agents are generally more water soluble than most other forms of CW, but are hydrolysed quickly to less toxic materials in solution. However, some of the hydrolysis products still contain a modicum of nerve agent activity. These hydrolysis products are very water soluble and likely to travel some distance in ground or surface water. Hydrolysis products may also be formed from certain organo-phosphorous (OP) insecticides, and so their detection is not always an indication of the presence of CW nerve agents. Under these circumstances an investigation of the use of OP's should be investigated in the surrounding area.

As phosgene has a very short half-life in water it is not generally analysed for. Detection of gross phosgene contamination or storage vessels is usually undertaken using an appropriate detection tube.

Throughout the site evaluation procedure consideration should be given to the potential risks from explosives and other conventional contaminants which are associated with MoD sites in addition to the CW agents. Further details of MoD sites are provided in Environment Agency R&D Technical Report P5-042/TR/01.

5.4 Site Evaluation Check-list

Have the specific uncertainties associated with CW sites been considered?
Is there an explosion risk and if so has this been evaluated?
Have the degradation products of CW agents been evaluated?
Has the presence of petroleum products and organic solvents been considered as a possible migration route for CW agents?
Has the possibility of small, localised, and possibly undetected sources of CW been considered?
Have both the acute and chronic toxicity effects of CW been considered?
Are more soluble breakdown products of CW (e.g. TDG) likely to be present. Do these represent a risk to controlled waters or to human health?

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. How can the remediation process be validated?

6.1 Scope

This section provides detail on the most applicable remediation technologies currently available (or likely to be available in the near future) on a commercial scale within the UK. It covers both the treatment of bulk CW agent as recovered from munitions etc. (Sections 6.2 and 6.3) and provides information to help the treatment of CW contaminated soils (Section 6.4). The intention of this section is to provide information to help the reader select a short list of appropriate remediation technologies and to highlight the key issues which will need to be considered in the remediation design. It does not provide detailed guidance on the selection process, nor on remediation design.

Based on the extent of current knowledge, the most significant environmental medium for CW contamination is considered to be the soil rather than groundwater or surface waters. Consequently the main emphasis within this section is on soil remediation.

A limited number of instances of contamination of groundwater by CW or CW degradation products have been encountered. Organic solvents are associated with the production of some CW or as used as dilutants for CW. Remediation of groundwater contaminated by such compounds is covered extensively in other guidance and so is not repeated within this document.

6.2 Principal Remediation Technologies for Bulk CW Agents

The 1993 Chemical Weapons Convention (CWC) requires that all remediation technologies for CW are:

- licensed, usually through the country's National Authority (in the UK this is a function of the DTI); and
- proven to destroy irreversibly CW material to a required level.

The CWC does not make any stipulations on the type of technology which must be used for CW destruction.

6.2.1 High temperature incineration

Currently the only CWC licensed remediation technology/facility in the UK is the high temperature incinerator at Porton Down. CW agents are routinely disposed of at this facility (although it is unable to deal with large quantities of CW agents) and it is primarily used for the destruction of limited volumes of weaponised and historically poorly disposed of CW.

The United States government is stated to be currently destroying its chemical weapons in an incineration process. Chemical agents are removed from munitions or bulk containers using remote, automated equipment. The chemical agents are collected in storage units and then incinerated at a minimum temperature of 2,700°F. The effluent then passes to an afterburner where it receives secondary incineration. Remaining trace concentrations of CW agents in gases are destroyed in this process. Effluent from the secondary incinerator is cooled and scrubbed in order to reduce particulate content.

Whilst this technology has been proven in the United States, incinerators in the UK are closely controlled under the Prescribed Process Regulations. An IPC authorisation (or future IPPC authorisation) would have to be modified to allow CW to be disposed of at a particular facility. It is unlikely that a commercial incinerator facility would go to the extent of attempting to modify its authorisation unless a substantial volume of CW material was to be provided for disposal.

6.3 Alternative Technologies

Alternative technologies broadly fall into the following groups (Picardi 1991):

- chemical processes;
- biological processes;
- photochemical processes;
- electrochemical processes;
- neutralisation;
- chemical reprocessing.

Most of these processes are currently at an experimental stage. Neutralisation (or detoxification) of both nerve agents and vesicants (mustard and lewisite) is being developed in both the USA and Russia specifically for use in the treatment of CW as the first stage of two part processes followed by either complete oxidation of organics to CO₂ and water (USA) or immobilisation of the reaction products by bitumenisation (Russia). Other disposal methods, such as supercritical water oxidation, are being adapted from use in commercial waste disposal. Many of these techniques are being developed specifically for the destruction of

large quantities of CW agent associated with the stockpiles in USA and Russia. The expense of building, testing and licensing some of these part-proven technologies purely for the disposal of CW-contaminated environmental waste in this country may mean few, if any, of these technologies ever become viable alternatives in the UK.

6.3.1 Chemical processes

Chemical degradation is the second CWC approved remedial process although there is no CWC licensed facility operating this technology in the UK. Generally this involves neutralisation or oxidation by one of a number of possible processes. Supercritical water oxidation uses water at great temperature and pressure and is a suitable technique for broad range of organic compounds together with oxidisable compounds such as cyanide and ammonia.

Steam gasification vaporises organic compounds in super heated steam. The evaporated waste is conducted to a steam gasification converter, with off gases being passed to absorbing filter beds.

Other pilot scale chemical techniques include:

- wet air oxidation;
- molten salt process;
- reductive degradation utilising metallic couples; and
- dechlorination.

6.3.2 Biological processes

As part of the US DOD programme to destroy its chemical arsenal, bioremediation of both Mustard and nerve agents is being seen as a possible viable alternative to incineration. Pilot scale studies to show the effectiveness of the process are well underway. In both cases the CW agent is hydrolysed by some other technology and the resulting solutions are then subject to the microbial degradation process. This is especially relevant for the disposal of Mustard which is toxic to micro-organisms and must be pre-treated to detoxify it before biotreatment can be effective. CW agents that contain arsenic present a different challenge to biotechnology since all arsenic compounds are toxic and therefore this method is not appropriate.

This work was piloted at the bench scale in the UK using soil contaminated with HT and was shown to be effective under certain conditions. It is possible that both *ex situ* or even *in situ* bioremediation may be appropriate to the remediation of many CW-contaminated sites where HT is the principal contaminant. Natural attenuation may also be applicable, though some form of augmentation, to provide aeration, nutrients and pre-treatment to detoxify and disperse large bulk quantities of CW agent may be required to assist the natural processes. The risks associated with this method must be thoroughly investigated for each site.

6.3.3 Photochemical processes

This is the main form of natural degradation of organophosphates (OPs), though it is unrealistically slow *in situ*. Photolysis is used in a number of hazardous waste treatment processes in conjunction with chemical catalysts and light at a wavelength greater than 290 nm. Studies on photochemical degradation are based primarily on pesticides and PCBs although it is believed that the technology is transferable to some CW agents.

6.3.4 Electrochemical processes

There are two major forms of this treatment technology applicable to CW. Electrodialysis concentrates charged ions from a waste stream and may therefore be more applicable to detoxifying soil than destroying CW. Electrochemical treatment uses metal ions as a coupling agent and facilitates anode oxidation, followed by alkaline hydrolysis. This has achieved some success with both CW and nuclear wastes, though the process is expensive to run.

6.3.5 Neutralisation

Neutralisation, by a combination of hydrolysis and oxidation, forms the basis of most individual decontamination procedures. A number of commercial systems are available for small scale decontamination, and the process is applicable to being scaled-up. Extensive studies have been performed in the UK and the US on optimising parameters for CW decontamination based on neutralisation. Hydrolysis is the reaction between water and a chemical species, leading to the breakdown of the species.

Both the UK and United States military use the powerful agent hyperchlorite to oxidise Mustard and VX should it be encountered during field operations. This is a highly exothermic reaction and although it has proved successful on a small scale in the field it has not been used as a large scale technique due to the strong base reactions.

6.3.6 Chemical reprocessing

This basically involves the use of CW as a chemical feedstock for the production of associated chemicals. However, the number and applicability of these associated chemicals is so limited as to discount this option. These are not applicable to dilute environmental CW waste.

6.4 Treatment of Contaminated Soils

Very little work has been done on developing methods for the treatment of CW agent contaminated soils. Within military operational areas CW contaminated ground is usually left to “weather” i.e. the CW agent is given time to disperse through evaporation into the air or by adsorption into the ground. Areas of gross contamination are treated with bleach or hypochlorite or are buried. None of these methods are appropriate for the remediation of historically contaminated sites.

The only method that has been used successfully for the treatment of soil contaminated with CW agents and their breakdown products is *ex situ* incineration. This is the only method available in the UK at present using the single licensed incinerator at Porton Down. The method is expensive and not suitable for CW agent residues containing arsenic or certain heavy metals.

Soil contaminated with CW agent and residues can be extremely hazardous since many of the chemical compounds contained therein are highly toxic and some are carcinogenic. All operations involving soil contaminated with these materials must therefore be carried out with great care for the safety of both workers and nearby populations. Any intrusive work, other than very minor surface sample taking, must be carried out inside a vapour containment system (VCS) operated under reduced pressure and fitted with a suitable dust and charcoal filter. All workers operating inside the VCS should wear appropriate full body and respiratory protection (see Section 7).

Since the incineration process is expensive, accurate measurement of contaminated volumes is important and this is normally carried out by sampling and analysis.

Bulk quantities of CW agent contaminated soil should be excavated and sealed within polythene bags and placed within suitable robust transport containers inside the VCS before being taken to Porton Down for disposal (see Section 7 for further details on packaging regulations).

6.5 Validation

The process of validating the success of a CW remediation exercise is, in principle, no different from the approach used for validating other conventional remediation projects which involve an initial excavation stage prior to the off site treatment or disposal of the contaminated material. This should include both a very detailed visual inspection of the excavation formation combined with the collection and analysis of a series of validation samples from the base and sides of the excavation in order to demonstrate that the contamination has been removed to a satisfactory extent.

7. HEALTH AND SAFETY

KEY QUESTIONS ANSWERED IN THIS SECTION

1. What specialist legislation is relevant?
2. What are the main hazards likely to be encountered?
3. What are the risks to health and safety of both operators and the public?
4. How can the major risks be managed to an acceptable level?
5. How can operators and the public best be protected?

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 CW 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

The Chemical Weapons Convention (CWC) and the corresponding UK enabling legislation, the Chemical Weapons Act (1996) (CWA) deals with matters pertaining to the control and destruction of CW agents and munitions. The legislation provides very little safety or environmental guidance other than to prohibit “*dumping in any body of water, land burial, or open-pit burning*” as disposal methods.

Both the CWC and the CWA strictly control the movements and disposal of CW munitions and/or quantities of CW agent once they have been found. Since the correct procedure for someone finding any items of old ordnance (whether CW or not) is to report them to the police, then this requirement should be taken care of automatically provided CW related items that are not munitions (such as sniff kits) are similarly reported.

At present, the only toxic waste incinerator in the UK that is licensed to take CW agents and contaminated soil is located at DERA Porton Down.

Consequently, there is no specialist safety or environmental legislation in the UK for working with CW agents and munitions. DERA Porton Down is the sole official source of advice to the UK Government for all matters pertaining to CW which include safety and protective measures to be taken to safeguard workers, members of the public and the environment. However, much guidance is available in the US from the Office of Safety, Health and Environment Agency (OSHEA).

7.3 Health and Safety Risk Assessment and Risk Management

7.3.1 Management systems

Safety issues should be fully integrated into the management of any CW related project and should not be considered as a separate subject. Safety is the responsibility of everyone within a project team and especially the project manager. However, it is strongly recommended that a Safety Officer should be appointed who has sole responsibility for providing safety and environmental advice to other project members who are then required to see that the advice is implemented. The Safety Officer should work closely with other team members to ensure the health and safety of both site workers and nearby populations.

Administrative controls are generally referred to in the context of work with CW as standard operating procedures (SOPs). SOPs are important because no operation can take place without people and, although people make mistakes, this risk can be minimised by implementing SOPs backed up by appropriate training.

An important principle of administrative controls is to minimise the numbers of people involved in any potentially dangerous operation. Additionally, all personnel should be physically fit, properly trained and competent to do the job required.

SOPs must be produced for all CW related operations together with an operation specific risk assessment.

7.3.2 Principles of CW risk assessment

The principles of risk assessment are the same for CW agent and explosive hazards as they are for any other hazards that are encountered in the working environment. In essence, the process of risk assessment follows a formal procedure which has to be carried out for each proposed operation. In this process, the possible hazards for the operation are first listed and given a rating ranging from severe to minimal (see Box 7.1 for specific definitions). The proposed operation is then examined and control methods are introduced to reduce the risks from these hazards to an acceptable level.

The first stage of the risk assessment process is therefore to identify the possible hazards and assess their likely severity.

Box 7.1 Definitions used in CW Health and Safety Risk Assessments

Hazard value: Potential for causing harm. Assigned a numerical value of severity

Risk: Hazard value multiplied by the probability of harm occurring

Risk assessments should be related to the specific operations which are being considered. For example, it is known that some types of explosive bursters can be very dangerous but the risk

of them causing harm depends entirely on what is done with them. If they were to be left buried in the ground then the risk is almost zero; it is only when they are dug up and handled that the risk increases.

7.3.3 CW agent hazards

CW agent hazards exist in a number of different forms such as a liquid skin contact hazard or a vapour or aerosol hazard. Of the CW agents commonly found to be present in old UK munitions, sulphur/oxygen Mustard (HT) presents both a liquid skin contact and a vapour hazard and phosgene presents a vapour hazard only. Although HT is very toxic it is not usually lethal except in the case of very high levels of contamination.

Volatile agents such as hydrogen cyanide (AC), cyanogen chloride (CK) and phosgene (CG) because of their high volatility can produce a lethal concentration of vapour very rapidly and are, in fact, the most hazardous of all the substances likely to be encountered. In addition, these compounds are poorly absorbed by the charcoal in military respirators which need to have special chemicals added to absorb them by chemical reaction. The added chemicals can be used up in situations of exposure to very high concentrations of CW and, in extreme cases, the respirator canisters or air filtration units can catch fire and be penetrated. For this reason, personnel who could possibly be exposed to very high concentrations of volatile CW agents should not wear respirators but should use Self Contained Breathing Apparatus (SCBA) as described below.

7.3.4 Explosive hazards

Explosive hazards exist from the high explosive components of old CW munitions.

Both explosive and CW agent hazards are present in buried CW munitions and together they warrant the most severe hazard rating. Therefore engineering controls should be used whenever possible to minimise the risk of causing multiple casualties and deaths from a single accident.

7.3.5 Risk management

The aim of all work with CW agents is contamination control. This is usually best achieved by a combination of engineering controls, such as barrier materials, vapour containment and decontamination together with administrative controls which, for example, aim to reduce the possibility of any spills during handling and to minimise the effects should they occur.

If it is not possible to eliminate the hazard, as is usually the case for investigation and remediation of CW contaminated sites, then engineering control measures are required to ensure safe working conditions. Toxic vapour containment represents one type of engineering control but remote operation e.g. evacuation of non-essential personnel, can be equally effective and is often more cost effective.

It is often best to use a combination of hazard containment and remote operation, or evacuation, to produce the most cost-effective control measures.

Whether vapour containment or distance is used to achieve safe operation with vapour hazards, it is necessary to understand and measure the micrometeorological (i.e. very localised weather conditions) situation in order to predict the extent of the downwind hazard. Hence micrometeorological measurement and forecasting, together with downwind hazard assessment, is an important part of all field operations with toxic chemicals.

If there is no possibility of using engineering controls, then Personal Protective Equipment (PPE) must be used to protect personnel. The correct selection and use of PPE can provide very effective protection against toxic chemical hazards although it is of very little use against explosive hazards.

The above examples of physical control measures should be used to control risks associated with CW in preference to administrative controls that rely on people following directions.

7.4 Specialist Working Methods and Equipment

Sites which may be contaminated with CW are generally all MoD or foreign forces sites, and the following health and safety requirements are specific to these sites or specific to CW. In addition, those working on-site must be aware of the Base Health and Safety Plan specific to the particular site.

7.4.1 Personal protective equipment (PPE)

PPE should be considered as a last resort after measures such as elimination of the hazard and engineering controls as described in the previous section have been considered and used. With demilitarisation of CW munitions, especially during the testing phase, elimination of the hazard is not possible because that is the object of the work. Although engineering controls should be used wherever possible, direct manual handling of CW agents will be inevitable and PPE will be required.

The types of PPE available range from the maximum level of protection possible with impermeable suits and self contained breathing apparatus (SCBA) to the still very effective air-permeable military suits and respirators. Impermeable suits and SCBA should be considered when very high vapour levels are expected or where there is the possibility of heavy liquid contamination of personnel. For low levels of vapour hazard and minimal risk of liquid contamination, then the military PPE is perfectly adequate. For low levels of vapour hazard but medium risk of significant amounts of liquid contamination, the military air-permeable suit can be worn augmented with a disposable PVC over-suit. PPE for use with CW should be specific to the task.

The most suitable type of PPE for a given operation should be selected according to the risk assessment carried out before any work begins. Whichever system of PPE is used, the work should be controlled by SOPs that should include an instruction to stop work if anyone should

become contaminated, withdraw from the source of contamination and decontaminate or change items of PPE as necessary. This may require the withdrawal of the contaminated person, or for a serious incident the entire team, from the work area and back through the decontamination station and treatment by the undressing team (see Section 7.4.3). Any of this equipment should be enclosed and disposed of if it becomes exposed to a significant level of contamination.

Clothing and masks used have been developed for protection against CW agents. Staff wearing specialist PPE can become heat stressed quickly and care must be taken to ensure they have sufficient rest periods and are monitored by other staff. In addition, PPE should be removed according to an approved SOP by the undressing team to ensure site staff are not exposed to contamination as PPE is removed.

Decontamination of PPE should be undertaken using 'super-tropical bleach' or bleach slurry solutions. Under no circumstances should dry powdered bleach/super chlorinated bleach be used as this reacts violently with Mustard causing it to catch fire.

A limited volume of information is available on aspects such as the correct PPE for each type of CW from sources such as the United States military (see Section 9 Sources of further information). Advice can be obtained on all issues relating to CW safety from DERA Porton Down.

7.4.2 Other equipment

Vapour Monitors

Special instrumentation including the Chemical Agent Monitor (CAM) has been developed to detect specific agents, which in the case of CAM is Mustard and nerve agents. These should be used on all sites with the potential to be contaminated with CW. This equipment is commercially available but requires specialist training and should only be operated by trained and certified staff. Calibration and maintenance must be rigorous, and the equipment should be 'fail safe'.

Although less convenient than the CAM, Draeger tubes can be used to detect a much wider range of substances in the vapour phase.

Vapour Containment

In areas where airborne CW would pose a risk to sensitive receptors then a Vapour Containment System (VCS) can be used. This is an excavation cover system which vents vapours derived from within via charcoal filters. Blast protection may also need to be employed where there is a potential for explosives to be present. This equipment is commercially available but requires trained operators to be used safely.

7.4.3 Working methods

Specialist training is required before staff undertake any form of CW agents assessment. Work should be undertaken within a group with members of the group monitoring each other during works.

A minimum of six site staff should be used on any MoD investigative works where CW agent or munitions are likely to be encountered. The first two staff are termed the 'clean and dirty' men. The 'dirty person' forms the excavation and is passed sampling jars, equipment etc. and is decontaminated and monitored by the clean person next to the excavation. A safety link person monitors the wind direction, and ensures that the 'clean' and 'dirty personnel' are working in safe conditions. There should be a two person dressing team who are responsible for ensuring that the 'clean and dirty personnel' get into and more importantly out of their PPE without becoming exposed to chemical agents. This involves the operation of a strict SOP. In addition to this, there should be an overseer whose role is to ensure that all the works are undertaken in a safe manner. This person may also have additional expertise in areas such as dealing with explosives.

The suspect site should be designated a 'dirty' area, fenced off and access should be strictly controlled. The sole entry to the dirty area should be via a formal clean/dirty boundary equipped as an undressing/decontamination station with foot-baths, vapour monitors and decontamination facilities. The undressing/decontamination station should be staffed by two trained undressers.

Meteorological conditions should be monitored to ensure that staff are not subject to heat stress; and also to monitor wind direction. The undressing/decontamination station should be located up-wind of the contaminated area and moved if necessary. Work should not be undertaken where wind speeds are below 3 m/s as wind direction is far more likely to be changeable at lower wind speeds and a change in wind direction can put decontamination workers at risk.

By this means, staff exiting from the dirty area can be monitored, decontaminated as necessary and undressed safely in an area up-wind and free from the risk of any down-wind vapour hazard. By the same criteria, any staff upwind of the undressing station should be in a clean area where the use of PPE is not necessary. Any site office or mobile laboratory should be sited in the upwind clean area or sufficiently far removed from the site so as to be safe from any vapour hazard arising from the work (safe distances should be calculated as part of the risk assessment).

Emergency CW release response procedures should be practised prior to site works commencing, and the airborne hazard should be monitored at all times during the works.

Local emergency services and hospitals should be briefed on the effects and mitigation measures of agents before work commences.

Contaminated articles should be consigned for disposal at DERA Porton Down and clearly labelled as dictated by the appropriate legislation. These standards should be in compliance with, International Civil Aviation Organisation Regulations (ICAO DOC 9284-AN/905), “Technical Instruction for the Safe Transport of Dangerous Goods by Air”, 1997-1998 Edition. The “European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR) and Protocol of Signature” (ECE/TRANS/115, VOL1 &2) should also be considered. All containers used should be marked with United Nations numbers confirming that they are fit for purpose.

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9. SOURCES OF FURTHER INFORMATION

The following organisations have this information online on the internet:

- Organisation for the Prohibition of Chemical Weapons (OPCW):

<http://www.opcw.nl/chemhaz/> (last accessed 20th December 2000)

European (Netherlands) based organisation providing information on toxicity and latest technologies for the destruction of CW, updates on countries complying with the 1993 Chemical Weapons Convention and news releases relating to Chemical (and Biological) Weapons.

In addition to information on this site, OPCW home page contains links to other relevant sites with additional information on the toxicity, medical treatment, decontamination and disposal of CW.

- US Army Chemical and Biological Defence Command (CBDCOM):

For general background:

<http://www.sbccom.apgea.army.mil/> (last accessed on 20th December 2000)

For Material safety data sheets by CW agent:

<http://www.sbccom.army.mil/RDA/erdec/risk/safety/msds/> (last accessed 20th December 2000)

Material Safety data sheets are available at this site for the following agents:

Sarin,
Soman
Tabun
VX
Mustard
Lewisite

This site also has details of health and safety equipment and PPE, detection equipment and methods for decontamination.

- SIPRI - Stockholm International Peace Research Institute

Full text version of the 1935 Geneva Protocol and Chemical Weapons Conventions, including details of historical agreements and conventions. Numerous links to other relevant sites.

<http://www.sipri.se/cbw/docs/cbw-hist-geneva-eng.html> (last accessed 20th December 2000)

- Chemical and Biological Arms Control Institute

<http://www.cbaci.org/> (last accessed on 20th December 2000)

- Her Majesty's Stationery Office (HMSO) (The Stationery Office)

Full text version of the 1996 Chemical Weapons Act can be found at The Stationery Office web site:

<http://www.publications.hmso.gov.uk> (last accessed on 20th December 2000)

- Chemical and Biological Defense Information and Analysis Center (CBIAC)

<http://www.cbiac.apgea.army.mil/> (last accessed on 20th December 2000)

- Mitretek systems

http://www.mitretek.org/mission/envene/site_map.html (last accessed on 20th December 2000)

This organisation provides detailed information relating to the more well known CW agents such as:

Mustard,
Lewisite,
Sarin,
Soman,
Tabun,
VX

It also contains detailed information relating to the physico-chemical properties, structure and toxicity of the above CW agents. In addition to the information on-line, the site contains numerous references to technical reports and scientific papers relating to this issue.

Appendix A: Definition of Chemical Weapons

1993 Chemical Weapons Convention

Article 2, paragraph 1 of The Chemical Weapons Convention 1993 defines Chemical Weapons as:

1. "Chemical weapons" means the following, together or separately:
 - (a) Toxic chemicals and their precursors, except where intended for purposes not prohibited under this Convention, as long as the types and quantities are consistent with such purposes;
 - (b) Munitions and devices, specifically designed to cause death or other harm through the toxic properties of those toxic chemicals specified in subparagraph (a), which would be released as a result of the employment of such munitions and devices;
 - (c) Any equipment specifically designed for use directly in connection with the employment of munitions and devices specified in subparagraph (b).

2. "Toxic Chemical" means:

Any chemical which through its chemical action on life processes can cause death, temporary incapacitation or permanent harm to humans or animals. This includes all such chemicals, regardless of their origin or of their method of production, and regardless of whether they are produced in facilities, in munitions or elsewhere.

(For the purpose of implementing this Convention, toxic chemicals which have been identified for the application of verification measures are listed in Schedules contained in the Annex on Chemicals.)

3. "Precursor" means:

Any chemical reactant which takes part at any stage in the production by whatever method of a toxic chemical. This includes any key component of a binary or multi-component chemical system.

(For the purpose of implementing this Convention, precursors which have been identified for the application of verification measures are listed in Schedules contained in the Annex on Chemicals.)

4. "Key Component of Binary or Multi-component Chemical Systems" (hereinafter referred to as "key component") means:

The precursor which plays the most important role in determining the toxic properties of the final product and reacts rapidly with other chemicals in the binary or multi-component system.

5. "Old Chemical Weapons" means:

- (a) Chemical weapons which were produced before 1925; or
- (b) Chemical weapons produced in the period between 1925 and 1946 that have deteriorated to such extent that they can no longer be used as chemical weapons.

6. "Abandoned Chemical Weapons" means:

Chemical weapons, including old chemical weapons, abandoned by a State after 1 January 1925 on the territory of another State without the consent of the latter.

7. "Riot Control Agent" means:

Any chemical not listed in a Schedule, which can produce rapidly in humans sensory irritation or disabling physical effect which disappears within a short time following termination of exposure.

8. "Chemical Weapons Production Facility".

- (a) Means any equipment, as well as any building housing such equipment, that was designed, constructed or used at any time since 1 January 1946:

- (i) As part of the stage in the production of chemicals ("final technological stage") where the material flows would contain, when the equipment is in operation:

- (1) Any chemical listed in Schedule 1 in the Annex on Chemicals; or

- (2) Any other chemical that has no use, above 1 tonne per year on the territory of a State Party or in any other place under the jurisdiction or control of a State Party, for purposes not prohibited under this Convention, but can be used for chemical weapons purposes;

or

- (ii) For filling chemical weapons, including, *inter alia*, the filling of chemicals listed in Schedule 1 into munitions, devices or bulk storage containers; the filling of chemicals into containers that form part of assembled binary munitions and devices or into chemical sub-munitions that form part of assembled unitary munitions and devices, and the

loading of the containers and chemical sub-munitions into the respective munitions and devices.

Chemicals Weapons Act 1996

General interpretation:

1. (1) Chemical weapons are:
 - (a) toxic chemicals and their precursors;
 - (b) munitions and other devices designed to cause death or harm through the toxic properties of toxic chemicals released by them;
 - (c) equipment designed for use in connection with munitions and devices failing within paragraph (b).
- (2) Subsection (1) is subject to sections 2(2) and (3), 10(1) and 11(2) (by virtue of which an object is not a chemical weapon if the use or intended use is only for permitted purposes).
- (3) Permitted purposes are:
 - (a) peaceful purposes;
 - (b) purposes related to protection against toxic chemicals;
 - (c) legitimate military purposes;
 - (d) purposes of enforcing the law.
- (4) Legitimate military purposes are all military purposes except those which depend on the use of the toxic properties of chemicals as a method of warfare in circumstances where the main object is to cause death, permanent harm or temporary incapacity to humans or animals.
- (5) A toxic chemical is a chemical which through its chemical action on life processes can cause death, permanent harm or temporary incapacity to humans or animals; and the origin, method of production and place of production are immaterial.
- (6) A precursor is a chemical reactant which takes part at any stage in the production (by whatever method) - of a toxic chemical.
- (7) References to an object include references to a substance.
- (8) The Convention is the Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction, signed at Paris on 13 January 1993.
- (9) This section applies for the purposes of this Act.

Appendix B - Tables

Table B.1 Chemical formulae for the principal CW agents produced/researched in the past in the UK

CW Agent	Type	Chemical Names	Synonyms
Mustard / Mustard gas	Blister agent / Vesicant	Bis(2-chloroethyl)sulphide	HD, HS, HB, HMD, HMB, Yellow cross & Yperite
Nitrogen mustard	Blister agent/ Vesicant	2-chloro-N-(2-chloroethyl)-N-ethylethanamine	HN-1
Oxygen mustard	Blister agent/ Vesicant	bis[2-(2-chloroethylthio)ethyl]ether	T, oxygen Yperite
Lewisite	Arsenical blister agent/vesicant	2-chlorovinyl dichloroarsine	Lewisite I (L)
(DA)	Arsenical agent/ vomiting	Diphenylchloroarsine	Blue Cross, Clark I
(DC)	Arsenical agent/ vomiting	Diphenylcyanoarsine	Clark II
Adamsite	Arsenical agent/ vomiting	Diphenylamine Chloroarsine	(DM)
Phosgene	Choking agent	Carbonyl chloride	(CG)
Hydrogen Cyanide	Blood agent	Hydrogen Cyanide	(AC)
CK	Blood agent	Cyanogen Chloride	(CK)
BBC	Lachrymator (tear agent)	a-bromobenzeneacetonitrile	Bromobenzyl cyanide

CW Agent	Type	Chemical Names	Synonyms
KSK	Lachrymator	Ethyl iodoacetate	None
Chloropicrin	Lachrymator	Trichloronitromethane	(PS)
CS	Lachrymator	O-chlorobenzylidene malonitrile	Pepper gas, Tear gas,
Tabun	Nerve agent	Ethyl N-dimethylphosphoramidocyanate	(GA), Dimethylphosphoramidocyanidic acid, ethyl ester,
Sarin	Nerve agent	Methylphosphonofluoridic acid, (1,methylethyl) ester	(GB)
Soman	Nerve agent	Methylphosphonofluoridic acid, 1,2,2-trimethylpropyl ester	(GD), Pinacolyl methylphosphonyl fluoride
VX	Nerve agent	Methylphosphonothioic acid, S-[2- [bis(1-methylethyl)amino] ethyl] O- ethyl ester	VX

Table B.2 Physical properties of common (past) UK CW agents

CW Agent	Appearance	Odour	Solubility	Persistence	Stability in storage / Environment
Sulphur Mustard	Oily liquid – colourless to yellow brown	Garlic or mustard odour	Almost insoluble in water, soluble in most common organic solvents	Intermediate/high	Stable in glass / steel, decomposes in contact with iron
Lewisite	Oily liquid, colourless to dark brown liquid	Geranium odour	Insoluble in water	High- 24 hours to 1 week, less in humid conditions	Stable in glass or steel, slowly decomposes in contact with iron.
Adamsite	Solid, yellow to dark green or brown		Insoluble in water, slightly soluble in organic solvents – decomposes in acetone	High	Extremely stable
DA	Solid, colourless to dark brown		Almost insoluble in water (<0.2%), moderate solubility in alcohol	High	Stable in absence of water, high rate of hydrolysis, leaves toxic breakdown products
DC	Solid, colourless to dark brown		Virtually insoluble in water (0.01%), soluble in dichloromethane	High	Stable, but less so than DA
BBC	Solid, yellow to brown, freezing point between 15 and 25°C	Odour of almonds	Virtually insoluble in water, soluble in most organic solvents,	Intermediate	Corrosive, unsuitable for storage, limited information about behaviour in the environment
KSK	Oily liquid, colourless to brown	Sweet	Virtually insoluble in water, soluble in organic solvents	Intermediate	Unstable, turns brown on exposure to air, decomposes on heating to give toxic fumes

CW Agent	Appearance	Odour	Solubility	Persistence	Stability in storage / Environment
CS	White solid, when burnt forms a colourless gas	Acrid, pepper-like smell		High	Very stable, absorbs into porous surfaces including soil
Tabun	Liquid, colourless to dark brown	Fruity odour, bitter almonds	Slightly soluble in water (7%), highly soluble in ether, ethanol and other common organic solvents	Intermediate	Stable when pure and stored in steel
Phosgene	Gas, colourless to light yellow or reddish brown	Mouldy hay when diluted in air	Insoluble in water (1%), soluble in organic liquids	Very low	Stable in absence of moisture. Very volatile
Hydrogen Cyanide	Colourless liquid (gas at 26°C)	Bitter almonds	Miscible in water and most organic solvents	Very low	Unsuitable for storage without stabilisers, volatile but dissolves in water to give hydrocyanic acid – persistent and stable
CK	Colourless gas	Odour of bitter almonds	Moderately soluble in water (8%), soluble in organic solvents	Very low	Stable in glass but not in steel
Chloropicrin	Colourless, oily liquid	Stinging pungent odour	Insoluble in water, soluble in organic liquids, lipids etc	Low	Very stable - limited information about behaviour in the environment

Table B.3 Principal raw materials for UK CW agents

CW Agent	Raw Materials
Mustard and sulphur mustard	Sulphur monochloride, Sulphur dichloride, ethylene thiodiglycol, thionyl chloride, hydrochloric acid, hydrogen chloride, 2-chloroethanol, ethylene oxide.
Lewisite	Acetylene and arsenic trichloride
Phosgene	Carbon monoxide and chlorine
BBC	Toluene, benzyl chloride, benzyl cyanide, sodium cyanide, bromine
CK – Cyanogen Chloride	chlorine and hydrogen cyanide
KSK	acetic acid, chlorine, sulphuric acid

Table B.4.1 Common breakdown products of WWI UK CW agents (where known)

CW Agent	Route of Decomposition	Decomposition Products	Persistence	Toxicity
Sulphur Mustard	Hydrolysis combustion	Thiodiglycol 1,4,dithiane 1,4,thioxane dioxins	Intermediate High	No, water soluble. Yes, hydrophobic, aromatic. Yes, hydrophobic, aromatic.
Chloropicrin	Hydrolysis Combustion	Chlorine and nitric oxide	Not known	Not known.
Lewisite	Hydrolysis	2-chlorovinyl arsenous acid which polymerises to give arsenic and arsenous oxides	Low, breakdown products are much more persistent	Highly toxic, carcinogenic, arsenous oxides remain in soils for many years.
Phosgene	Hydrolysis in water	Carbon dioxide and hydrogen chloride	Very low	No, much less of a problem than other agents when in soils, rapid degradation by hydrolysis.
BBC	Hydrolysis	Bromoacetamide, diphenylsuccinonitrile	Intermediate	Not known.
CK	Hydrolysis	Cyanuric chloride, cyanic acid, hydrogen chloride, carbon dioxide, ammonium chloride	Very low	Volatile, not particularly toxic.
KSK	No hydrolysis in water	Not known	Not known	Not known.

Table B.4.2 Common breakdown products of WWII UK CW agents (where known)

CW Agent	Route of Decomposition	Decomposition Products	Persistence	Toxicity
Sulphur Mustard	Hydrolysis Combustion	Thiodiglycol 1,4,dithiane 1,4,thioxane dioxins	Intermediate High	No, water soluble. Yes, hydrophobic, aromatic. Yes, hydrophobic, aromatic.
Lewisite	Hydrolysis	2-chlorovinyl arsenous acid which polymerises to give arsenic and arsenous oxides	Low, breakdown products are much more persistent	Highly toxic, arsenous oxides remain in soils for many years.
Phosgene	Hydrolysis in water	Carbon dioxide and hydrogen chloride	Very low	No, much less of a problem than other agents when in soils, rapid degradation by hydrolysis.
BBC	Hydrolysis	Bromoacetamide, diphenylsuccinonitrile	Intermediate	Not known.

Table B.5 Breakdown products from the historical disposal of WWII CW agents

CW Agent	Route of Decomposition	Breakdown Products	Properties / toxicity
Mustard	Hydrolysis	Thiodiglycol	Harmless, water soluble
Mustard	Oxidation with bleach/incomplete combustion	Dithianes Thioxanes Dioxins	Hydrophobic, aromatics, odorous, toxic and persistent
Lewisite	Hydrolysis	2-chlorovinyl arsenous acid which polymerises to give arsenic and arsenous oxides	Highly toxic, arsenic compounds are carcinogenic
Lewisite	Oxidation with bleach/incomplete combustion	Arsenic compounds	Highly toxic, arsenic compounds are carcinogenic