

Chemical works

pharmaceuticals manufacturing works

Industry Profiles, together with the Contaminated Land Research Report series, are financed under the Department of the Environment's contaminated land research programme.

The purpose of these publications is to provide regulators, developers and other interested parties with authoritative and researched advice on how best to identify, assess and tackle the problems associated with land contamination. The publications cannot address the specific circumstances of each site, since every site is unique. Anyone using the information in a publication must, therefore, make appropriate and specific assessments of any particular site or group of sites. Neither the Department or the contractor it employs can accept liabilities resulting from the use or interpretation of the contents of the publications.

The Department's Contaminated Land Research Report series deals with information needed to assess risks; procedures for categorising and assessing risks; and evaluation and selection of remedial measures.

General guidance on assessing contaminated land and developing remedial solutions which is complementary to the Department's publications is provided by the Construction Industry Research and Information Association (CIRIA).

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DOE Industry Profile

Chemical works: pharmaceuticals manufacturing works

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Preface

DOE Industry Profiles provide developers, local authorities and anyone else interested in contaminated land, with information on the processes, materials and wastes associated with individual industries. They are not definitive studies but they introduce some of the technical considerations that need to be borne in mind at the start of an investigation for possible contamination.

Every site is unique. Investigation of a site should begin with documentary research to establish past uses. Information on the site's history helps to focus a more detailed investigation. This knowledge needs to be supplemented by information on the type of contamination that may be present and where on site it may be found. Profiles give information on the contamination which might be associated with specific industries, factors that affect the likely presence of contamination, the effect of mobility of contaminants and guidance on potential contaminants.

The date when industrial practices first commenced on a site and its location are important clues in establishing the types of operations that may have taken place, so each profile provides a summary of the history of the industry and its likely geographical spread within the United Kingdom.

Profiles should be read with the following reservations in mind:

- individual sites will not necessarily have all of the characteristics described in the profile of that industry;

- practices can vary between sites and change over time;

- as practices change, problems of possible contamination may also change;

- the profile may refer to practices which are no longer followed, and may omit current practices which avoid contamination.

The risks presented by contaminated sites depend on the nature of the contaminants, the targets to which they are a potential threat (such as humans or groundwater) and the routes or pathways by which they reach these targets. The current or proposed use of a site and its environmental setting are crucial in deciding whether treatment is necessary and if so, the methods to be used. Some sites may not need treatment.

The information in profiles may help in carrying out Control of Substances Hazardous to Health (COSHH) assessments for work on contaminated land - see Health and Safety Guidance Note HS(G) 66 *Protection of workers and the general public during the development of contaminated land*, Health and Safety Executive, 1991, and *A guide to safe working practices for contaminated sites*, Construction Industry Research and Information Association, 1995.

Note: the chemical names given to substances in this profile are often not the modern chemical nomenclature, but the names used historically for those substances.

Chemical works: pharmaceuticals manufacturing works

1. Background

The pharmaceutical manufacturing industry makes products used for the treatment of human and animal diseases and ailments. These include patented and generic prescription only medicines, over the counter medicines, dental products, animal treatment and husbandry products, and substances such as vitamins and hormones which may be incorporated into foodstuffs.

1.1 History

The earliest records of medicinal plants and minerals are those of the ancient Chinese, Hindu and Mediterranean civilisations. Many drugs employed in ancient times are still beneficial in medicine today. Pharmaceutical practice improved markedly in the 16th and 17th Centuries, with the first pharmacopoeia (list of drugs and medicinal chemicals with directions for use) appearing in 1546. The first such list in the United Kingdom was the London Pharmacopoeia, published in 1618, which was applied throughout England. In 1617 the Society of Apothecaries was formed, thereby establishing their activities as a distinct profession.

The modern pharmaceutical industry began in the 19th Century with the discovery of highly active medicinal compounds, which were then manufactured on a large scale, replacing the herbal medicines of earlier times. In 1841 the Pharmaceutical Society of Great Britain was established, placing education and training of the pharmacist on a scientific basis. The Pharmacy Act of 1868 introduced Schedules of Poisons and introduced the term 'pharmaceutical chemist'. From then on, only registered chemists and druggists have been allowed to supply poisons to the public.

Anaesthetics were first employed in 1842; alkaloid compounds were also isolated from plant sources in this period. In 1865 the modern era of antiseptic surgery began in Britain with the use of phenol to prevent infections. In 1900 benzocaine replaced cocaine as the principal ingredient of local anaesthetics. Other major developments included the discovery of antibiotics, starting with penicillin in 1941.

The pharmaceutical industry now works within the tight regulatory framework of the Medicines Act 1968 and subsequent European legislation (see Section 4).

1.2 Location

There are around 300 pharmaceutical companies in the United Kingdom, of which only about 100 are of any significant size. About 15% of these firms have interests in all three of the principal market areas: prescription medicines, over the counter medicines and animal health. There is no general trend for the location of pharmaceutical companies by sector, although problems associated with the disposal of effluent from chemical and fermentation plants may influence site selection. There are three main centres of manufacture with over 50% of them located in London and the Home Counties, over 15% in Sussex and Hampshire and nearly 10% in Lancashire, Greater Manchester and Cheshire.

2. Activities

Pharmaceuticals are manufactured in two principal stages, primary and secondary. Primary processing is the extraction and production of the active ingredient from its sources. It includes processes such as organic synthesis, biological processing, extraction of animal and vegetable substances and inorganic chemical preparation. Secondary processing is the conversion of the active ingredient into products suitable for administration.

The common products of secondary processes include:

Tablets or powders	These may be coated so that the stomach acid does not destroy the active ingredient.
Capsules	Capsules consist of an outer gelatine covering enclosing the mixture of active substance which is in granular or powder form.
Liquids	These may be in the form of solutions, suspensions, emulsions or gels. They may be aqueous or ethanol based. Syrups are commonly formulated for administration to children.
Creams and ointments	These usually consist of an oil in water emulsion (cream) or a water in oil emulsion (ointment).
Aerosols	These contain inhalable products or products suitable for external use.
Injectables	A liquid or suspension which must be completely free of particulate matter and micro-biological contamination.

The two stages may take place on the same production site, on adjacent production sites, or on separate distant sites. In some cases they are carried out by different sectors within the industry or separate companies within a pharmaceutical group.

2.1 Raw materials delivery, handling and storage

The raw materials used in primary processes are generally received on site in kegs or drums in either powder or liquid form. Organic solvents such as toluene and methanol are typically received into bulk storage tanks, but some raw materials used in smaller quantities are received in drums. Because it is inert, nitrogen gas is often used to replace air in storage vessels, plant and dryers when they contain flammable, volatile materials. It is also used as a coolant for freeze-drying products and may be supplied in liquefied form from a liquid storage facility or on-site air separation plant. Acids and alkalis may be received in bulk for use in manufacturing processes, in wastewater neutralisation and in wet scrubbers. In addition, fuel oil may be stored for steam generation systems.

For both primary and secondary processes, the majority of raw materials are delivered by lorry or bulk tanker, depending on the materials and quantities used.

Drums, kegs and bags are transferred from the lorries to the storage area by fork-lift truck, typically on pallets to aid transfer. Raw materials delivered by road tanker are either pumped or fed under pressure to bulk storage vessels, usually by coupling the tanker to vessel inlet transfer pipework.

Drums and kegs are normally handled within the storage area by fork-lift trucks which may be modified with drum clamping equipment. Materials in bags and small kegs may be transferred manually within the storage area and to various parts of the works. Materials received by bulk road or rail tankers are typically not manually handled (except in emergencies) once in the storage tank. Bulk stored materials (eg solvents) are transferred within the works by pumping. Gaseous materials such as nitrogen are transferred using the available storage pressure.

2.2 Primary processes

The processes used in the bulk production of the active ingredient may involve fermentation, chemical synthesis or extraction. To ensure the safety and efficiency of pharmaceutical products, the process for manufacturing the active ingredient must be carefully controlled to ensure consistent standards of purity and quality. This is because all drugs are active in very small doses and some drugs are very potent. In addition, impurities can adversely affect the action of a drug, eg can produce adverse side-effects or can be toxic.

2.2.1 Chemical synthesis

Most pharmaceutical active ingredients are produced by organic synthesis from a range of raw materials, principally organic compounds. Organic chemical synthesis reactions usually involve the weighing and mixing of raw materials and transference into batch reactors. The mixture may be in a dispersed form, ie in a solvent. These solvents are almost exclusively organic and may be chlorinated or non-chlorinated. In up-to-date primary production plants, solvents are recovered extensively from waste air streams, wastewater streams, and from completed reactions.

Solvents are used in reaction and purification. Reaction solvents facilitate close molecular proximity for all reactants and are often selected for their boiling point. Where the boiling point equals the desired reaction temperature, heat is continuously supplied to keep the reaction mass boiling and the solvent vapours are continuously condensed and returned to the reactor.

The reacted products are typically washed with water or solvents, or both in turn, prior to filtration. After filtration the residual solids are often dried under nitrogen. If required, further purification can be carried out using a variety of operations including colour removal by adsorption onto activated carbon and filtration, crystallisation and evaporation techniques, as well as further washing and drying operations.

Common products prepared using synthetic chemistry include barbiturates, codeine, caffeine, salicylic acid and its derivatives, and vitamins.

Further information on processes for the production and use of a number of synthetic organic compounds can found in the HMIP Chief Inspector's Guidance Notes referred to in Section 4.

2.2.2 Fermentation

The utilisation of the growth of micro-organisms, under controlled process conditions, to produce pharmaceutical chemicals is generally performed using fermentation techniques. Common fermentation products include antibiotics such as penicillins, steroids, vitamins and biological products such as antitoxins and toxins. These processes mostly involve taking the initial culture (inoculum), weighing and mixing the nutrients and other additives, and transferring them all to a fermentation tank. The fermentation can either be anerobic or aerobic. The culture is then filtered to remove the micro-organisms from the raw liquor containing the product. Occasionally the required chemical is contained within the micro-organism and, in this case, the cell walls are broken before filtration.

The product is cooled and subjected to solvent extraction in order to concentrate it in a single medium prior to primary purification processing. Colour can be removed from the mixture by adsorption onto activated carbon granules. The carbon is then removed by filtration. Other processes may include crystallisation and drying operations. Primary purification is followed by final purification, where the product is either crystallised from a liquid or dried, followed by grinding and blending from dry operations, as in the case of penicillin.

2.2.3 Extraction

A diverse range of pharmaceutical drugs is produced by extraction from natural and biological sources, such as plants, animal glands and parasitic fungi.

2.3 Secondary processes

The active substance from primary manufacture must be presented as an accurate dose in a form which can be conveniently administered to the patient eg tablets, capsules, creams, ointments, ampoules for injection. Diluents may be added to the active substance to achieve the correct dose and other ingredients may be necessary to ensure that the final dosage form is palatable, stable and behaves exactly as intended. For example, tablets must be hard enough to withstand transport but they must disintegrate easily after administration to the patient. Finally, the product must be packed appropriately.

Formulation, filling and packaging plants have changed significantly over the last 20 years. Their layout has improved with better understanding of the requirements for movement of materials and personnel, and the provision of a healthy working environment.

Secondary production consists of a series of unit operations arranged in a specific sequence, carried out in batches of 50 to 800 kg. The process units are, in general, dedicated for a period of time to a series of batches, after which they are cleaned and re-used for another product. The main steps in the operation are:

• Sieving and milling	The active ingredient is usually supplied already milled in the required physical form. Other raw materials are sieved and milled to ensure that the physical size of the solid components is correct and uniform.
Weighing	This is usually manual but may be automated for large quantity ingredients in modern facilities.
Mixing and blending	When making tablets and capsules the active substance must be thoroughly mixed with the diluents and other ingredients to manufacture a stable, palatable and effective final product. The mix must be homogenous to ensure each tablet or capsule contains the same amount of active substance. Blending may be dry or wet. Wet blending operations use water where possible; otherwise syrups or solvents are used. Starch or sugar is generally added to the blend in order to dilute the active ingredient to the required concentration. Similarly for creams and ointments, mixing must give a completely uniform product which will not separate on storage and will deliver the drug effectively when applied to the skin. The powdered active ingredient is mixed with the carrier and sometimes heated, to produce a homogeneous product with the correct flow properties.
Granulation	Granulation, or agglomeration, is a precursor to the majority of tablet compression processes and to some encapsulation processes. Powders are often unsuitable for pressing since the individual components may dissociate too easily and generate a lot of dust. Granulation can be wet or dry.
Drying	Drying operations take place in tray ovens, fluidised beds, or dryers using vacuum, tumbling, spraying, freezing, infrared or microwave techniques.
Tablet pressing	Tablets are produced in tablet presses by direct compression of the blended materials. Modern tablet presses compress 8 000 to 12 000 tablets per minute and provide automatic control and monitoring of tablet weight. Some tablets are printed with a butanol/ethanol based ink.
Tablet coating	Coating imparts physical strength to the tablet and delays break-up once swallowed. Aqueous or solvent-based coatings may be used which are typically sprayed onto the tablet and then dried. Cellulose may be applied, for example, to prevent the material from being digested in the stomach. Traditionally sugar coatings have been used; these have generally been superseded by polymer films.

Filling and packing Automated mechanical methods of packaging include filling bottles and making blister packs. Aerosol cans are filled, weighed and leak tested. Traditionally, chlorofluorocarbon (CFC) propellants have been used. Nitrogen gas is a substitute. Butane is now widely used in externally applied products but it is hazardous and flammable. Alternative technologies are emerging which preclude the need for chemical propellants. The 'envirospray' makes use of the reaction between two additives, citric acid and sodium bicarbonate, to release carbon dioxide which forces out the product. This propellant formula is being increasingly utilised in pharmaceutical applications.

2.4 Transfer of finished products

The quantity of finished products varies considerably depending on the market targeted by the particular company. Intermediate formulations may be produced in large quantities in either liquid dispersion or solid form. Final products can be in a variety of forms, eg liquids, tablets, powders and aerosols.

Active substances must be transported in a safe and secure way. Sealed steel kegs with polythene liners are normally used which may be transported by road, rail, sea or air. Final transfer of products from storage areas for transport is usually by fork-lift truck.

The finished pharmaceutical product is normally packed directly in the form in which it will be dispensed to the patient. The packs are collated into outer cardboard boxes for shipment to wholesalers. Occasionally, bulk tablets and capsules may be transported to a separate packaging unit in sealed steel, fibreboard or plastic kegs.

2.5 Ancillary activities

Pharmaceutical production facilities typically have their own electrical substation, which in the past may have contained polychlorinated biphenyls (PCBs). The environmental risks posed by PCBs have required pharmaceutical companies to undertake a systematic programme of replacement to eliminate them from their sites. A few transformers and other electrical components may contain PCBs but this is rare.

Sites will have steam generating systems and may also generate some of the electricity used in the manufacturing process. Natural gas is the most commonly used fuel source but oil may be stored both as a primary and back-up fuel supply. Sites using large quantities of nitrogen for inerting purposes may also have liquid nitrogen generation or storage facilities.

Primary manufacturing plants may have their own wastewater treatment plant.

2.6 Wastes

On combined sites, waste from primary and secondary production may not be differentiated and may share a common disposal pathway from the site.

For economic and environmental reasons, almost all primary pharmaceutical plants operate solvent recovery systems that purify contaminated solvents for re-use. These facilities usually contain distillation columns and may also include extraction facilities. In secondary manufacturing there are far fewer solvent recovery systems. This is because the volumes and the concentrations of solvent used are far lower, often precluding economically-viable recovery and, in many cases, allowing discharge directly to the environment. Organic wastes from secondary processing do not lend themselves to recovery because they are characterised by intermittent release and variable composition as a result of the batch nature of secondary processing.

The handling of waste varies and may have changed over the life of the company; waste management also depends on the size of the company. Wastes may be stored in a variety of drums and vessels in either properly designed storage compounds with appropriate bunding and in-floor drains to wastewater treatment facilities, or out in the open on grassed areas in direct contact with the ground. Such wastes are stored until sufficient quantities are amassed for cost effective disposal by an outside contractor. Many wastes containing volatile organic compounds are transported by bulk tanker for incineration.

Modern plants may have wastewater treatment facilities which use chemicals such as acids, alkalis and calcium compounds. There is evidence that in the past certain effluents, particularly solvents, may have been accidentally spilled or leaked directly to the ground and allowed to soak away. Waste materials may also have been disposed of in landfills constructed on site which were unlikely to have been properly lined. Such wastes may include inert material (eg glass or plastic containers, floor sweepings etc) but also chemicals, particularly tarry residues from still bottoms. When solvent recovery units were first used, residues may have been deposited directly on the ground surface. There may also have been considerable potential in the past for leakage of effluents eg acids and solvents, to occur from collection tanks and pipework. Such tanks may also have been prone to spills caused by their being overfilled.

3. Contamination

The contaminants on a site will largely depend on the history of the site and on the range of materials produced there. Potential contaminants are listed in the Annex and the probable locations on site of the main groups of contaminants are shown in Table 1. It is most unlikely that any one site will contain all of the contaminants listed. It is recommended that an appropriate site investigation be carried out to determine the exact nature of the contamination associated with individual sites.

3.1 Factors affecting contamination

Contamination on any present or former pharmaceutical manufacturing works depends upon the age of equipment, the control measures applied and any prior uses of the site. Because of the nature of the products, current handling procedures can be expected to be secure. Careful containment of primary processes that involve highly active substances is driven by the Control of Substances Hazardous to Health (COSHH) Regulations. However, accidental spillages may have occurred occasionally over the operational life of the site.

Contamination may occur at locations of effluent vessels, pipework and inadequately-contained waste storage areas, or where wastes were stored in direct contact with the ground. Surface water soakaways on any site with a long history of industrial use are also likely to be prime areas for contamination. On-site landfills used for waste disposal may also be contaminated. At sites carrying out primary processes the waste may contain inorganics, organics, metals and metal compounds.

Organic solvents are mainly of concern in primary production sites, as they are used in extraction processes, organic synthesis, separation and purification processes. Solvents are used, though in far smaller volumes, in secondary production. Solvent contamination is most likely to occur around bulk storage and loading areas, with a smaller potential in areas utilising the solvent and in areas of distribution pipework.

Acids and alkalis are used in general chemical processes, both primary and secondary, and for wastewater treatment. Contamination from acid and alkali storage may also occur in bulk storage areas for these materials and their associated pipework.

Fuel oils and coal would be used in both primary or secondary production for steam generation. Contamination could occur near underground storage tanks or coal storage areas.

3.2 Migration and persistence of contaminants

Of particular concern with respect to the spread of contamination will be the release of organic solvents. Once in the ground, oils and solvents flow downwards under gravity but leave behind a residue held within the unsaturated soil. The magnitude of the risk to groundwater depends on the depth of the water-table and the soil structure and properties. Generally, the higher the organic matter and clay content within the soil, the greater the adsorption of organics and the lower the mobility. Conversely the greatest migration of contaminants will occur in coarse-grained sands and gravels with little organic matter.

The soluble components will dissolve in the groundwater and migrate in the groundwater flow. Where surface water is present there is a risk of contamination by any of the contaminants listed in the Annex, especially the more soluble organics such as the alcohols, acetone, ethyl acetate and phenol. Phenol itself is very soluble and can migrate considerable distances from its source. Phenols can also permeate water supply pipes of polymeric materials such as PVC and can attack the joints of metal pipes which are usually made of PVC or plastic sealing compounds.

The less soluble aromatic compounds which become adsorbed onto clay or organic matter will provide on-going sources of water pollution long after the original source has been removed, by continuing to desorb and dissolve into the soil water. Some organic contaminants will naturally degrade but some of these (eg benzene, toluene, tars and petroleum hydrocarbons) may persist owing to unfavourable environmental conditions for biodegradation.

The non water-soluble solvents and oils that are less dense than water will float on the water-table surface. However, chlorinated solvents are more dense than water and will tend to migrate to the bottom of aquifers. Since they move under the influence of gravity, their migration may be opposite to the general groundwater flow. They are persistent chemicals and can render groundwater unsuitable for public supply at low concentrations.

A further problem frequently encountered with volatile solvents or oils, is that vapours moving through unsaturated soils may subsequently dissolve into the groundwater. If these vapours evaporate directly to the atmosphere, they can accumulate in poorly ventilated confined spaces, such as drains, and present a fire or explosion hazard.

The movement of metals through the soil is significantly retarded by the presence of clay minerals and organic matter. The solubility of some metals may increase under acidic conditions (eg copper, zinc and lead). In other cases the relationship is more complex. For example, trivalent chromium is more soluble under acidic conditions, whereas the solubility of hexavalent chromium is increased under both acidic and alkaline conditions. Arsenic may become more soluble at higher pH levels.

Wind dispersion of contaminated soil may be a further transport mechanism, but it is unlikely to be a major factor at pharmaceutical sites unless there is gross surface contamination by some of the less mobile contaminants, eg metals or asbestos. Asbestos is not soluble or biodegradable.

PCBs and some of the halogenated organics are fat-soluble and have a propensity to accumulate in food chains.

Acid spillage near buildings may affect the integrity of concrete/cements used in foundations.

Natural biodegradation may result in significant removal of oils and some organic compounds (eg those of lower molecular weight and those of higher aqueous solubility). The heavy fractions of oils are often persistent.

Biodegradation processes in soils can be influenced by a number of factors, namely moisture content, oxygen concentration and pH values, acting separately or in combination. For example low moisture content reduces microbiological activity, while high moisture content can reduce oxygen penetration and possibly lead to anaerobic soil conditions. Such conditions enhance the biodegradation of some materials, eg chlorinated compounds, while aerobic conditions are needed to biodegrade many oils. Also, low pHs tend to reduce the bacterial population and encourage fungal activity; at pHs lower than 5, microbiological activity is much reduced. The presence of heavy metals also inhibits micro-organisms. Because of these factors, at high concentrations in soil, even relatively non-persistent compounds may not biodegrade readily. It is possible for partial microbial transformation to produce a substance more toxic or mobile than its parent.

4. Sources of further information

4.1 Organisations

For information concerning the pharmaceuticals manufacturing industry in the United Kingdom, the following organisations should be consulted:

Association of the British Pharmaceutical Industry
12 Whitehall
London
SW1A 2DY

Association of Information Officers in the Pharmaceutical Industry
Pfizer UK Ltd
Sandwich
Kent
CT13 9NJ

Chemical Industries Association Limited
Kings Buildings
Smith Square
London
SW1P 3JJ

Society of Chemical Industry
14/15 Belgrave Square
London
SW1X 8PS

4.2 Sources of further information concerning the activities described in this profile

Austin, G T. *Shreve's chemical process industries*. 5th Edition. London, McGraw-Hill, 1984.

Dragun, J. *The soil chemistry of hazardous materials*. Silver Spring MD (USA), Hazardous Materials Control Research Institute, 1988.

Case study including information relevant to this profile:

Paul V. *Bibliography of case studies on contaminated land: investigation, remediation and redevelopment*. Garston, Building Research Establishment, 1995.

Legislation specific to the pharmaceutical industry:

Medicines Act 1968.

Charlesworth, F. A *The guide to the European directives concerning human medicines*. Association of the British Pharmaceutical Industry, June 1992.

Information on researching the history of sites may be found in:

Department of the Environment. *Documentary research on industrial sites.* DOE, 1994.

4.3 Related DOE Industry Profiles

Chemical works: organic chemicals manufacturing works

Waste recycling, treatment and disposal sites: solvent recovery works

4.4 Health, safety and environmental risks

The Notes issued by the Chief Inspector of Her Majesty's Inspectorate of Pollution (HMIP) provide guidance for the processes prescribed for integrated pollution control in Regulations made under the Environmental Protection Act 1990. Series 4 of the Process Guidance Notes covers many aspects of the Chemical Industry Sector. Of particular relevance are:

Her Majesty's Inspectorate of Pollution. *Pharmaceutical processes.* Chief Inspector's Guidance to Inspectors. Process Guidance Note IPR 4/9. London, HMSO, 1993.

Her Majesty's Inspectorate of Pollution. *Batch manufacture of organic chemicals in multipurpose plant.* Chief Inspector's Guidance to Inspectors. Process Guidance Note IPR 4/5. London, HMSO, 1993.

Her Majesty's Inspectorate of Pollution. *Pollution control in pharmaceutical secondary production processes.* PECD 7/9/597. Department of the Environment, 1993.

The Control of Substances Hazardous to Health (COSHH) Regulations 1994 and the Management of Health and Safety at Work Regulations 1992 are available from HMSO. Information on relevant health and safety legislation and approved codes of practice published by HSE publications are available from Health and Safety Executive Books, PO Box 1999, Sudbury, Suffolk, CO10 6FS (telephone 01787 881165), as well as HMSO and other retailers.

Information on the health, safety and environmental hazards associated with individual contaminants mentioned in this profile may be obtained from the following sources:

Sax N and Lewis R. *Hazardous chemicals desk reference.* New York, Van Nostrand Reinhold Company, 1987.

Verschueren K. *Handbook of environmental data on organic chemicals.* 2nd Edition. New York, Van Nostrand Reinhold Company, 1983.

Howard P H. *Handbook of environmental fate and exposure data for organic chemicals.* Vols I and II. USA, Lewis Publishers, 1990.

4.5 Waste disposal and remediation options

Useful information may be obtained from the Department of the Environment series of Waste Management Papers, which contain details of the nature of industrial waste arisings, their treatment and disposal. A current list of titles in this series is available from HMSO Publications Centre, PO Box 276, London, SW8 5DT.

Publications containing information on the treatment options available for the remediation of contaminated land sites, prepared with the support of the Department of the Environment's Research Programme, can be obtained from National Environmental Technology Centre Library, F6, Culham, Abingdon, Oxfordshire, OX14 3DB.

A full list of current titles of Government publications on all aspects of contaminated land can be obtained from CLL Division, Room A323, Department of the Environment, Romney House, 43 Marsham Street, London, SW1P 3PY.

Advice on the assessment and remediation of contaminated land is contained in guidance published by the Construction Industry Research and Information Association (CIRIA), 6 Storey's Gate, Westminster, London, SW1P 3AU.

Annex Potential contaminants

The chemical compounds and other materials listed below generally reflect those associated with the industry and which have the potential to contaminate the ground. The list is not exhaustive; neither does it imply that all these chemicals might be present nor that they have caused contamination.

Primary and secondary processes

Organics

Non-halogenated solvents

toluene
methanol
acetone
butyl acetate
dimethyl formamide
benzene
ethyl benzene
ketones
ethanol
isopropanol
isobutanol
pyridine

Halogenated solvents

dichloromethane
chloroform
carbon tetrachloride
fluorobenzene
trifluoroacetic acid
1,2-dichloroethane

Coal tar

polycyclic aromatic hydrocarbons (PAHs)

Fuel oil

alicyclic, aliphatic, paraffinic and olefinic hydrocarbons

Polychlorinated biphenyls

Inorganics

Acids

sulphuric
hydrochloric

Alkalis

sodium hydroxide

Calcium compounds

lime-based residues

Asbestos

Primary processes only

Organics

Tar residues	polycyclic aromatic hydrocarbons (PAHs)
Alcohols	methanol ethanol
Phenolic compounds	phenol aminophenol isopropylated phenol
Esters	eg pentaerythritol esters
Organic acids	acetic acid and its salts
Chlorinated aromatics	chlorobenzene chlorobenzene substitutes chlorinated phenols
Aromatic hydrocarbons and their compounds	eg xylene (used for synthesis of beta blockers) styrene oxide (used in animal health products)

Inorganics

Cyanides

Sodium salts	sodium chloride sodium sulphate
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Metals and metal compounds

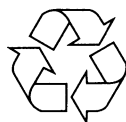
zinc *
zinc chloride
manganese*
arsenic*
chromium*
copper*
mercury*
(*catalysts)

Table 1 Main groups of contaminants and their probable locations

Chemical works: pharmaceuticals manufacturing works

Contaminant	Location							
	Bulk storage tanks, pipework and pumps (inc loading areas)	Production areas	Effluent tanks, pipework and pumps (inc wastewater treatment)	Solvent recovery plants	Solid/drummed waste storage areas	On-site waste disposal	Fuel storage	Electrical substations and transformers
Metals			(ZnCl)					
Inorganic compounds								
Acids and alkalis								
Asbestos								
Organic solvents								
Tars from primary processes								
Fuel oils and coal								
PCBs								

Shaded boxes indicate areas where contamination is most likely to occur



Recycled paper

DOE Industry Profiles

Airports

Animal and animal products processing works

Asbestos manufacturing works

Ceramics, cement and asphalt manufacturing works

Chemical works: coatings (paints and printing inks) manufacturing works

Chemical works: cosmetics and toiletries manufacturing works

Chemical works: disinfectants manufacturing works

Chemical works: explosives, propellants and pyrotechnics manufacturing works

Chemical works: fertiliser manufacturing works

Chemical works: fine chemicals manufacturing works

Chemical works: inorganic chemicals manufacturing works

Chemical works: linoleum, vinyl and bitumen-based floor covering manufacturing works

Chemical works: mastics, sealants, adhesives and roofing felt manufacturing works

Chemical works: organic chemicals manufacturing works

Chemical works: pesticides manufacturing works

Chemical works: pharmaceuticals manufacturing works

Chemical works: rubber processing works (including works manufacturing tyres or other rubber products)

Chemical works: soap and detergent manufacturing works

Dockyards and dockland

Engineering works: aircraft manufacturing works

Engineering works: electrical and electronic equipment manufacturing works (including works manufacturing equipment containing PCBs)

Engineering works: mechanical engineering and ordnance works

Engineering works: railway engineering works

Engineering works: shipbuilding, repair and shipbreaking (including naval shipyards)

Engineering works: vehicle manufacturing works

Gas works, coke works and other coal carbonisation plants

Metal manufacturing, refining and finishing works: electroplating and other metal finishing works

Metal manufacturing, refining and finishing works: iron and steelworks

Metal manufacturing, refining and finishing works: lead works

Metal manufacturing, refining and finishing works: non-ferrous metal works (excluding lead works)

Metal manufacturing, refining and finishing works: precious metal recovery works

Oil refineries and bulk storage of crude oil and petroleum products

Power stations (excluding nuclear power stations)

Pulp and paper manufacturing works

Railway land

Road vehicle fuelling, service and repair: garages and filling stations

Road vehicle fuelling, service and repair: transport and haulage centres

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