

Engineering works

*electrical and electronic equipment
manufacturing works (including works
manufacturing equipment containing PCBs)*

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

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

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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.

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

1. Background

Electrical and electronic equipment covers an extremely diverse range of products, from large scale electricity generating and transmitting plant through to micro-electronic components. Electronic engineering is the manufacture of equipment which operates on very low current; electrical engineering deals with high power equipment.

This profile deals with the common processes which are characteristic of the industry and with the following specific products:

- printed circuit boards
- electronic components
- insulated wire and cable
- batteries and lighting equipment.

The use of polychlorinated biphenyls (PCBs) by the electrical industry is highlighted on pages 2-3.

1.1 History

1.1.1 Nineteenth Century

The requirement of the electric telegraphy system for reliable, constant voltage power led to the development of the battery. The Leclanché cell, introduced in 1866, formed the basis of the first 'dry' cell. The large scale introduction of electromagnetic generators and dynamos from 1870 onwards made electrical energy readily available and stimulated the development of secondary or storage batteries.

Carbon arc lamps were used in lighthouses from 1857 but the general use of tungsten filament lamps did not occur until the early 20th Century.

The industry was diversified by the establishment, in 1878, of the first British telephone company and the development in 1895/6 of the 'wireless' telegraph.

1.1.2 Twentieth Century

The birth of the electronics industry began with the invention of radio communications and the use of thermionic valves as amplifiers. The industry was stimulated by the demand for radio communications during the First World War. The BBC was given an exclusive license to transmit 'wireless' programmes in 1922.

The Second World War saw the development of circuit boards and radar. After the War the television broadcasting and manufacturing industry expanded significantly. The basis for the modern electronics industry was the invention of the transistor in 1947. Transistors steadily replaced valves and by 1958 a few transistors, resistors and other simple components were being integrated on the surface of single silicon wafers. The development of integrated circuits was rapid during the 1960s and

early 1970s, increasing the range of application for semi-conductor devices. The development of the microprocessor led to the rapid growth of the computer and other electronic industries.

1.2 Location

The electrical and electronic engineering industry has expanded rapidly this century, particularly since the 1970s. In 1924 there were approximately 2300 manufacturing sites, which increased to just over 4000 in 1968. By 1989 about 11 200 sites were in operation, declining to about 10 100 in 1993 as a result of the economic recession.

The main centre for the production of electrical and electronic equipment has always been South East England but there are important areas in the West Midlands, North West and South West.

The electronics industry is usually located in new industrial estates outside towns and cities, particularly in areas served by good road and rail links. These are often in the home counties or near new towns such as Bracknell, Telford and Milton Keynes.

Census of Production data from 1935, 1968 and 1993 indicate that the great majority of establishments employed fewer than 25 people. However, a small percentage of works were very large.

Polychlorinated biphenyls (PCBs)

The major use of polychlorinated biphenyls (PCBs) in the United Kingdom was in the electrical industry, almost entirely as dielectric fluid in a comparatively small number of transformers and in very large numbers of capacitors for alternating current (AC) electrical use.

PCBs were imported from abroad in the 1940s and were produced in the United Kingdom between 1951 and 1976.

Formulations

There are 209 different polychlorinated biphenyls, each individual compound containing between one and ten chlorine atoms attached to a biphenyl molecule. Commercial mixtures of PCBs were sold under various trade names, the most common of which were *Aroclor* (a series), *Clophen*, *Fenchlor*, *Kanechlor*, *Pyrochlor* and *Phenochlor*. The number following the trade name provides an indication of the degree of chlorination: apart from *Aroclor 1016*, the last two digits of the *Aroclor* series correspond to the percent by weight of chlorine present. A common PCB-containing product class used in transformers and capacitors was *Askarel*. Different *Askarels* consisted of various *Aroclors*, neat or mixed with trichlorobenzene or tetrachlorobenzene. Commercial preparations of PCBs may also have been contaminated with impurities, particularly polychlorinated dibenzofurans (PCDFs).

Polychlorinated biphenyls (PCBs) continued

Transformer and capacitor manufacturing works

In the 1950s, there were 11 manufacturers of power transformers and 28 manufacturers of distribution transformers. By the mid-1970s, there were 10 major manufacturers using about 3000 tonnes per year of the most highly chlorinated PCBs. The use of PCBs in transformers ceased in the late 1970s. Less than 1% of the transformers manufactured in the United Kingdom between 1955 and 1976 contained PCBs.

Between 1954 and the late 1970s almost all manufacturers producing AC capacitors used PCBs. In the early 1970s there were four major manufacturers of large capacitors. They produced 150 000-200 000 units and used about 600 tonnes of the less chlorinated PCBs each year. By 1980 the use of PCBs in capacitors had ceased.

Restrictions

In the United Kingdom, the manufacture and use of PCBs is restricted under the Control of Pollution (Supply and Use of Injurious Substances) Regulations 1986 (S I 1986 No 902) (as amended). Use of PCBs in certain existing equipment, mainly for dielectric applications in transformers and capacitors, subject to limits for smaller capacitors, was exempted from the ban. However, continued concern about the effects of PCBs on sea mammals led to agreement by the Third North Sea Conference in 1990 to phase out and destroy remaining identifiable PCBs by the end of 1999. The United Kingdom is taking forward an Action Plan to meet this commitment and EC Environment Ministers agreed a framework in December 1994 for a draft Directive on PCBs which, among other requirements, sets thresholds for action.

Replacements

Early replacements for PCBs as dielectric fluids included monobenzyl toluene, dibenzyl toluene and phenyl xylene. Currently, the most commonly used substances are polydimethylsiloxane (PDMS) and pentaerythritol esters. Dry transformers and capacitors are now available.

For more information on PCBs, see Section 4.

2. Manufacturing processes

2.1 Electrical and electronic equipment

The principal raw materials associated with the production of electrical and electronic equipment are described below. The materials and compounds associated with the industry which could give rise to contamination are listed in the Annex.

2.1.1 Raw materials

There are a number of materials specific to each particular product but main raw materials used by the industry are:

Conductors

These are mainly copper or copper alloys (in electrical wire and contact points), aluminium (in switch gear, generators and motors) and carbon (in brushes and

contacts). Super-conductors are a relatively recent innovation and utilise lead, titanium, tin, germanium and niobium.

Other metals are used for specific purposes, for example iron, nickel, cobalt and manganese (in electromagnets) and precious metals (in electrodes and thermocouples).

Semi-conductors

These are normally based on a silicon substrate but other materials, such as elemental germanium or gallium arsenide, may be used.

Insulators

The three main types of insulators are:

Solid insulators Oil-impregnated paper, vulcanised natural rubber or synthetic plastics.

Gas dielectrics

Liquid dielectrics Initially used in large scale power generation and transmission equipment but the range of applications expanded, for example in transformers and capacitors (see Section 2.3).

2.1.2 Production processes

The manufacture of generic groups of products are described in the following sections. These groups are joined to form electrical circuits for the intended end use. These vary from small scale assemblies, such as those using active electronic components on circuit boards, to power transmission using large transformers and high voltage cables.

The production processes and waste materials associated with the manufacture of structural parts, cabinets and housing for electrical and electronic equipment are not covered here; refer to the profile on mechanical engineering and ordnance works (see Section 4).

2.2 Printed circuit boards

A printed circuit is an electronic sub-assembly consisting of an insulating board with a conductor laminated on to it.

2.2.1 Raw materials

In addition to the raw materials detailed listed in Section 2.1.1, the following materials are used in the manufacture of printed circuit boards and electronic sub-assemblies:

Plastics Thermoplastic and thermosetting polymers, reinforced with paper, glass fibre cloth, cotton fabric or nylon, and incorporating fire retardants.

Plating chemicals For electroless copper deposition and electroplating.

Photoresists Organic substances applied as liquids and thin adhesive films, which polymerise on exposure to

	ultraviolet light and protect the underlying surface from acids or solvents which are used as etchants.
Etchants	Used to dissolve unwanted areas of the solid surfaces of circuit boards.
Bonding agents	Epoxy resins.
Cleaning agents	A variety of chlorinated and fluorinated organic solvents, water-based cleaners and detergents.
Encapsulating materials	To protect assembled components mounted on circuit boards.

2.2.2 Production processes

Manufacture of printed circuit boards

Multi-layer circuit boards are built from layers of glass fibre fabric impregnated with epoxy resin which are bonded using heat processes.

The insulating board is then plated by electroless copper deposition in the following stages:

deburring of holes and surfaces, normally using rotating brushes, and degreasing with aqueous alkaline cleaning solutions or organic solvents

acid pickling

activation by dipping in successive chloride solutions

copper deposition by dipping in strong alkaline solutions containing copper ions.

Next, the board is 'metallised'. This involves the selective building up of metal layers, usually copper, on the coated board. Other metals used are nickel, tin/nickel alloy, lead, tin, gold and rhodium. Photoresists are then applied to protect substrates during etching or coating processes in the form of a liquid 'ink', or by photoprinting.

Etching, the removal of unwanted copper, is achieved by dipping in or spraying with acidic chloride solutions. Tin/lead plate is removed with ammoniacal etchants.

Finally, wiring is embedded from a spool into an adhesive layer on the board.

Combining printed circuit boards and electronic components

The three main assembly methods are described below.

Through hole assembly

The wire leads of discrete electronic components are inserted through holes drilled in the circuit boards and are soldered to the conductive track. Resin smear caused by the drilling is removed by dipping the multi-layer board in acids or alkaline permanganate solution. The latter solution is regenerated by the addition of persulphate. More recently, a plasma desmearing process using a mixture of tetrafluoromethane and oxygen has been developed. This method is now being superseded by surface mount technology.

Surface mount assembly

Leadless components are positioned on to connecting pads and then soldered.

Hybrid assembly

This involves a combination of film technologies. In thin film assemblies, passive components are manufactured by vapour deposition and selective etching, while in thick film assemblies they are manufactured by printing, drying and firing pastes.

After assembly, soldering fluxes are removed by the following cleaners:

Water or water/alcohol mixtures	Used to remove low molecular weight organic acid fluxes.
Chlorinated/fluorinated hydrocarbon solvents	To remove rosin fluxes and alkyl acid phosphate fluxes.
Aqueous alkaline cleaners	Also used to remove rosin flux residues.
Glycol ether	Used to remove rosins which cannot be saponified.

Finished assemblies are usually encapsulated in resinous materials. The most common method is 'conformal coating' in which successive thin transparent resin coats are applied by brushing, dipping or spraying to form an electrically insulating protective barrier.

2.3 Active electronic components

Active electronic components switch, modulate and amplify electrical signals. They include components constructed from semi-conducting materials in the form of discrete devices such as transistors, opto-electronic devices such as light emitting diodes, integrated circuits, temperature sensors and vacuum or gas filled electron valves and tubes.

2.3.1 Raw materials

Active electronic components comprise conducting, semi-conducting and insulating materials. Metals such as copper, aluminium, nickel, titanium, silver and gold are used as conductors. There are two types of semi-conductor, elemental and compound. Silicon is the most common elemental semi-conductor, with germanium also being important. Compound semi-conductors are composed of combinations of compounds such as gallium arsenide and indium phosphide. Insulators vary according to the application but include metal oxides, plastics and, in the past, mica. A variety of photoresists, developing agents, etchants and chemical cleaning agents are used in the fabrication of semi-conductor devices and circuits. The deposition of conductor and semi-conductor layers frequently involves gaseous and liquid precursors such as silicon tetrachloride and alkyl-metal compounds.

2.3.2 Production processes

The basic steps in the production of transistors and integrated circuits are as follows:

Growth of the semi-conductor crystal and slice preparation to create the substrate wafer using etching and polishing processes.

Growth of thin layers of material on the chosen semi-conductor substrate surface (for example silica on a silicon substrate).

Formation of patterns to define the shape of the transistors and electrical connections.

Doping (the controlled introduction of impurities) to create near-surface regions responsible for the electrical behaviour of the device/circuit.

A microprinting process known as photolithography is used to create the desired pattern. The pattern is first created on a glass photomask plate using computer controlled photoreduction techniques. It is then transferred to the substrate by selective exposure of a photoresist coating to ultraviolet light, in a similar process to that used in printed circuit board manufacture. The unwanted photoresist is stripped and the underlying surface film etched using either wet chemical or active gas plasma methods, selectively exposing areas of the underlying semi-conductor surface ('resist holes'). Dopants are introduced, usually either by high temperature diffusion or by ion implantation. The former involves heating the wafer to a high temperature followed by exposure to a gas stream containing the appropriate dopant which enters the resist holes and diffuses into the surface of the semi-conductor substrate. Ion implantation involves exposure of the resist holes to high energy beams of dopant ions.

Depending upon the application, patterns and holes created by photolithography will be overlain by other layers. These layers may be formed by a variety of techniques such as chemical vapour deposition, physical vapour deposition and vapour phase epitaxy (a method of growing crystals of a semi-conducting material on to a substrate of the same material). A large scale integrated circuit may require up to fourteen photolithography steps, six layer definitions and four ion implantations during the fabrication process.

2.4 Transformers and capacitors

Transformers are designed to increase or decrease the voltage of an alternating current. They consist of two or more coils (windings) on a single magnetic core. A capacitor is an electrical component which is capable of storing and discharging electrical energy. It consists of conductors separated by an insulator. Large capacitors are used to smooth out any 'shock' fluctuations on industrial power supplies.

2.4.1 Transformers

Raw materials

The main raw materials used in the manufacture of transformers are:

Steel or iron	Used to form the transformer core.
Copper or aluminium	Used as the windings.
Heat resistant plastic or varnish	For windings insulation. In the past, cotton was used.
Oil	Used as a coolant. The most common are polydimethylsiloxane (PDMS) and pentaerythritol

esters. In the past mineral oils were used. PCBs were used from the 1940s to 1970s.

Chlorinated solvents For transformer cleaning.

Non-chlorinated solvents Used for cleaning purposes.

Lubricating oils

Production

Steel is cut into the required shape and stacked to form the transformer core. Low voltage, high voltage and tertiary windings are lowered into the transformer core. After the connections are made, the completed core and windings are fitted with a tank. The unit is dried and filled with transformer oil. Only a small proportion of transformers used PCBs as dielectrics; these were generally more highly chlorinated biphenyls than those used in capacitors. Upon the completion of final assembly operations, the transformer is sealed and tested.

2.4.2 Capacitors

Raw materials

The raw materials used in the manufacture of capacitors are:

Steel or aluminium Used to form the terminals, bushings and cases.

Chlorinated solvents As degreasing agents.

Polypropylene To form components. Previously a mixture of polypropylene and Kraft paper was used and, before the 1960s, Kraft paper alone.

Various organic compounds Used as capacitor impregnates. These commonly include polydimethyl siloxane and pentaerythritol esters which replaced PCBs in the 1970s. These in turn had superseded chlorinated naphthalenes in the 1950s.

Production

The terminals, bushings and aluminium or steel cases are fabricated and degreased. Two capacitor plates of aluminium or tin foil are produced. The foils and the dry constituent of the dielectric are wound together into packs, which are wrapped in paper and placed in the metal case, the lid of which is welded on. The capacitor is now a sealed unit, apart from an impregnation hole in the casing.

The capacitor is then placed in a tank for vacuum drying under heat. The tank, containing the capacitor unit, is then flooded with liquid in an impregnating vessel (typically containing a volume of 5500 litres). Following impregnation, a vacuum is applied to remove excess liquid from the capacitor. The capacitor is then removed from the tank and vessel, the hole is sealed and the capacitor is degreased.

2.5 Insulated wires and cables

2.5.1 Raw materials

The main raw materials are conducting metal wire and insulating material, which are usually manufactured off site.

In the past, the raw materials consisted of copper, lead, rubber, paper, cotton, bitumen and mineral oils.

The metal wires now used are made of copper, copper alloys and aluminium. The insulating materials are generally flexible thermoplastics or elastomers. Synthetic oils have now largely replaced mineral oils in oil-filled power cables. Some wiring system cables use mineral insulation in the form of magnesium oxide powder inside a copper sheath.

A recent development in telecommunications is the use of optical fibre cables containing fused silica fibres coated with a double silicone rubber layer and a protective layer of acrylic polymer or loosely fitted polypropylene tube.

2.5.2 Production processes

The bare metal wires are subjected to physical and chemical (acid) cleaning processes, and are then bound together or wound to form a cable. Some cables are then wrapped in paper impregnated with mineral oils or paraffin wax, and insulated by extrusion of the insulating material along the cable. Transmission cables are filled with an oil-based coolant. High voltage electrical transmission cables also have paper and lead sheath armour.

2.6 Batteries

There are two types of battery: primary non-rechargeable batteries, from which only one continuous or intermittent discharge may be obtained; and secondary rechargeable batteries (accumulators), which may be recharged to approximately their original state. Primary batteries provide power from an irreversible chemical reaction and include Leclanché cells, alkaline manganese cells and mercury cells. Secondary batteries include lead-acid cells and nickel-cadmium cells. Lithium based systems have recently been developed for both primary and secondary cells. Special high temperature batteries are also available which use non-aqueous electrolytes.

2.6.1 Raw materials

These include metals, metal salts and oxides, acids, alkalis and a variety of insulation and protective packaging materials including steel, nylon, paraffin wax, bitumen and plastics.

2.6.2 Production processes

The integral parts of a cell are the cathode, anode and electrolyte.

Modern Leclanché cells comprise a zinc anode, a synthetic manganese dioxide cathode and a solution of ammonium chloride and zinc chloride as the electrolyte. The zinc is normally alloyed with lead or cadmium and rolled into a thin sheet prior to forming into cups which hold the electrolyte (in cylindrical cells). Finely divided carbon is combined with manganese dioxide to form the cathode mix. The electrolyte is immobilised as a paste, impregnated into pulp board liners or paper coated with a gelling agent. Corrosion inhibitors may be added to the electrolyte. Connecting carbon rods are usually manufactured from carbon, bitumen and sulphur.

Zinc chloride cells are similar but have a pure zinc chloride electrolyte. Alkaline manganese cells use concentrated potassium hydroxide as the electrolyte, to

which zinc oxide powder has been added to saturate the solution with zincate ions. The same type of electrolyte is used in mercury cells, which have zinc anodes formed by an amalgamation of pressed zinc powder, and mixed mercury oxide/graphite cathodes. Zinc-silver oxide cells have silver oxide instead of mercury oxide.

Lead-acid batteries are lead/lead oxide cells incorporating a sulphuric acid electrolyte. The electrodes are usually manufactured by pasting a mixture of finely milled lead oxide and sulphuric acid on to a lead alloy grid. Alternatively, cathodes may be made by enclosing the oxide paste around an axial lead connecting rod in a perforated *Terylene* or glass fibre tube, or by the electrochemical oxidation of the surface of pure cast sheet lead. Cathodes include additives such as barium sulphate or ligno-sulphonic acid derivatives. The electrodes undergo 'forming' (initial charging) to convert the electrode material into its fully charged condition. The lead oxide of the anode is changed into 'sponge' lead by this process. Connector straps are welded to lugs on the trimmed electrodes before assembly between synthetic polymer separators.

Nickel-cadmium batteries are cadmium-nickel oxide cells which use a potassium hydroxide electrolyte, sometimes including a small amount of lithium hydroxide. There are two types of electrode, 'pocket plate' electrodes (in which the active materials are retained within interlocking pockets in finely perforated nickel-plated steel sheet) and sintered electrodes (in which the active materials are distributed within the pores of a sintered nickel mass). The active material for pocket plate anodes may be produced either by the electrochemical co-reduction of cadmium sulphate and iron sulphate, or by the dry mixing of cadmium oxide or hydroxide with magnetic iron oxide or iron powder. The active material may be pelletised with various waxes or oils, prior to insertion into the pockets. Sintered anodes are formed by pressing and sintering nickel powder on to a supporting nickel screen. The active materials are infused into the anode by impregnating the sinter with cadmium nitrate solution followed by its thermal decomposition, or by cathodic polarisation of the sinter in a molten cadmium nitrate bath. The active material in the cathodes is generally nickel hydroxide which has been precipitated from a solution of nickel sulphate. It also incorporates cobalt and barium hydroxides and graphite.

Other examples of secondary batteries include iron-nickel oxide cells, zinc-nickel oxide cells and zinc-silver oxide cells. Recently developed lithium cell systems use solid, soluble or liquid cathode reagents, some using lithium salts in organic solvents as electrolytes.

2.7 Electric lighting equipment

2.7.1 Raw materials

The manufacture of electric lighting equipment shares many common processes with other forms of electrical equipment production. The unique feature of lighting equipment is the lamp. Electric lamps produce light in one of three ways:

Thermoluminescence

This is obtained from a heated filament. The most commonly used lamp is the tungsten filament light bulb consisting of a thin coiled tungsten wire supported on metal rods which are inside an evacuated glass bulb. The bulb contains a small amount of inert gas such as nitrogen or argon to prevent blackening.

Electric discharge

This is caused by the passage of electricity through a gas or vapour. The most common is the low pressure sodium discharge lamp (used for street lighting) containing the vapours/gases of sodium and neon or sodium and mercury with argon or xenon. In addition, fluorescent powders may be added to give specific types of radiation. High pressure mercury-vapour lamps consist of a quartz or glass bulb containing mercury and argon, with electrodes of tungsten-wire helices which are coated with electron emissive materials. Metal iodides may be incorporated within the discharge tube, or the glass bulb may be coated with fluorescent phosphors to give improved light emission.

Fluorescence

This involves the emission of ultraviolet radiation as a result of an electrical discharge and its conversion to visible light by a phosphor coating inside the lamp. An important component of the starter units of fluorescent lights is a small capacitor which, in the past, may have contained PCBs.

2.7.2 Production processes

Lamp manufacture involves the following basic processes:

Production and assembly of the light-emitting source and mountings from component parts (mostly comprising metals).

Coating the bulb surface or light emitting source with fluorescent powders as required.

Inserting the light source and mountings inside the bulb.

Extracting the air from inside the bulb and inserting gas or vapour, as required, followed by sealing, usually by fusing the glass bulb.

Soldering the external contacts.

2.8 Wastes

General solid wastes and sludges include:

Absorbent materials used to mop up spilled and leaking liquid dielectrics and impregnates (which may have in the past included PCBs) and cleaning fluids.

Finely divided copper and plastics, from drilling and deburring circuit boards, and dusts containing metals and metal oxides from milling and grinding operations.

Off-cuts and swarf from the machining of iron, steel, copper and aluminium.

Off-cuts of insulator materials, leads and wires (bituminous wastes may have been produced in the past).

Scrap or off-specification assemblies and circuit boards, reject battery cells and casings, spacers and electrodes, reject lamps and faulty components (for example capacitors), broken glass (mercury and phosphors may be present), scrap capacitor windings and capacitors.

Packaging materials.

Sodium sulphate from the regeneration of alkaline permanganate desmearing solutions.

Precipitated sludge from effluent treatment/pH adjustment.

Sludges from pickling, desmearing, etching, developing, plating, cleaning and storage tanks and baths.

PCB contaminated oil from retrofilled transformers.

Metal transformer/capacitor casings which could have been in contact with PCBs.

Liquid effluents include:

Spent pickling, desmearing, degreasing, etching, polishing, cleaning and developing solutions and solvents.

Contaminated rinse waters and spent metallising solutions. These may be rich in acids, metallic residues or PCBs, depending on what components have been cleaned.

Electrolytes etc from recycled battery cells, and spent solutions used to prepare and purify active electrode materials.

Exhausted 'forming' acids used to prepare lead-acid battery electrodes.

In general, waste management policies have advanced significantly over the last 20 years, and waste minimisation, recycling, recovery and safe disposal to licensed landfills or incinerators are current good practices.

Aqueous wastes may contain significant quantities of solvents and oils, and oil traps or separators may be used to prevent spills reaching the sewer system. However, in the past, wastes may have been buried on site, disposed of to local water courses or burned as fuel.

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

Sites may have been occupied for a considerable period of time and therefore may have been associated with a succession of technologies. The industry has

produced a wide range of potential contaminants, particularly oils and solvents, of which PCBs are of particular concern.

The scale of use of materials is not necessarily a guide to the likelihood of contamination. For example, in the past, it was not uncommon for works which used only small quantities of oils and solvents to discharge waste fluids into soakaways, trenches, conduits or drains leading to the sewer, which may have leaked. Misuse of solvents to clean floors may have allowed them to seep into the ground.

3.1.1 PCBs

PCBs are most likely to occur on sites where they were used in the manufacture of transformers and capacitors, and at works where these items were in operation. Contamination may be present in raw material storage areas, production areas used for filling transformers and capacitors, on-site waste disposal areas and in stores for finished and reject products. Other sources of possible contamination are the on-site disposal of contaminated materials, for example absorbent materials used to mop up spills. Soil contamination by some PCBs may not be readily distinguishable from contamination by other types of oil.

3.1.2 Oils

Contamination is most likely to be found around storage areas for raw materials and wastes, along the lines of drains, around sunken floor sumps in metal working and dielectric filling areas and at on-site disposal areas.

3.1.3 Solvents

Solvents are most likely to be found around storage areas for waste and virgin solvents, along the lines of underground drains, and at the locations of on-site soakaways or sludge storage and disposal areas. Spillages may have occurred during transfer between storage tanks and delivery vehicles.

3.1.4 Metals

Metals and their salts may be encountered around waste storage areas, on-site disposal areas, storage areas for plating chemicals and electrode materials, and around sunken sumps and floor drains in etching and plating process areas. Contamination may occur as a result of spillages of machining swarf stored in skips, the accumulation and subsequent on-site disposal of metals in floor sweepings from metal working areas, the on-site storage and disposal of various sludges, and leaks and spillages of plating chemicals. A further source of contamination may be in air ducting and filtration systems where salts of toxic heavy metals can accumulate.

3.1.5 Acids and alkalis

Acids may be associated with sludges from pickling, electroplating, electrode forming and acid effluent dump tanks. Alkaline sludges containing residual hydroxides, carbonates, silicates, borates and phosphates can originate from alkaline aqueous degreasing tanks, plating baths, alkaline effluent tanks and effluent neutralisation tanks.

3.1.6 Asbestos

Asbestos may have been used in pipe lagging or insulation, or as cladding or roofing materials in buildings. Contamination may have arisen following decommissioning of plant or buildings or the disposal of waste materials on site.

3.2 Migration and persistence of contaminants

The fate of contaminants once they have entered the ground depends on a range of factors such as the phase of the compound, solubility, and ground permeability. For instance, contaminants within the upper soil layer may be affected in a number of ways, such as downward leaching or run-off from rainwater, volatilisation, adsorption, chemical transformation and plant uptake.

The higher the natural organic matter and clay content within the soil, the greater the adsorption of the organic chemicals, leading to a decrease in contaminant migration. Therefore, the greatest degree of migration will occur in coarse-grained sands and gravels with little natural organic matter. The less soluble compounds which become adsorbed on to clay or organic matter will provide on-going sources of water pollution long after the source has been removed, by continuing to desorb into the soil-water. The risk from organic chemicals to current and potential water supplies may therefore be considerable. Lateral movement through the soil, either in the dissolved or free phase, may also affect surface water.

Biodegradation processes in soils can be influenced by a number of factors, namely moisture content, oxygen concentration and pH, 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, for example 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. As a result of these factors, at high concentrations in soil, even relatively non-persistent compounds may not biodegrade readily.

3.2.1 PCBs

PCBs are chemically inert, resistant to acids, alkalis and corrosive chemicals, and are highly persistent. Their persistence in the environment increases with the degree of chlorination. They are thermally stable and of low aqueous solubility. They are soluble in fats, oils and some organic solvents, and accumulate within living organisms where they cause adverse metabolic changes.

The nature of PCB contamination within soil is likely to be different from the original commercial preparation. This is believed to result from the greater volatilisation of the lower chlorinated components, although there may also be slow biodegradation in soil. The greater the degree of chlorination, the less volatile the component and the more resistant it is to microbiological degradation processes under normal conditions. Under anaerobic conditions, however, there is evidence that significant but slow losses of higher chlorinated PCBs may occur through biodegradation.

Because of their limited mobility, PCBs do not generally present a major threat to groundwater. However, because they tend to bioaccumulate in the fatty tissue of aquatic organisms and transfer along food chains, even very low concentrations present a hazard to surface water ecosystems. PCBs can be adsorbed on to stream sediments where they may form a long term source of contamination.

Significant contamination is likely to be localised around the area of release unless disturbed by demolition, clearance or site redevelopment. PCBs may be

transported through adsorption on suspended solids in surface water run-off from contaminated soils. Their mobility may be increased where there is significant ground contamination by organic solvents/oils in which they are relatively soluble, for example 1,1,1-trichloroethane and mineral oils.

3.2.2 Oils

Surface water may be contaminated by run-off of oil. Soil and groundwater may be contaminated by the downward flow of oils or rainwater percolating through oil-saturated ground. Large or sudden releases of oils can seep down to the underlying water table where they can spread out over the surface of the groundwater. Certain oils, for example silicone oils, which are more dense than water will sink. The base constituents of mineral oils generally have very limited water solubility, although certain synthetic oils, for example polyglycols, will dissolve in water. Soluble synthetic oils and oil-water emulsions pose the greatest threat to water quality.

3.2.3 Solvents

Solvents are characteristically highly mobile and volatile liquids. Hydrocarbon and halogenated solvents have limited but nonetheless significant water solubility. Surface water may be affected by run-off from contaminated soil, and the seepage of solvents or solvent-contaminated groundwater into drains which discharge into surface watercourses. Once in the ground, these organic compounds may flow downwards under gravity, but leave behind a residue held within the unsaturated soil. This residue may contaminate rainwater percolating through the ground and therefore may present a long term source of groundwater pollution.

If they reach the water table, light organic compounds (for example hydrocarbon solvents and most oils) float on top of the groundwater, spreading out as a covering film. This floating layer acts as a contaminant pool which may continue to supply pollutants to the water.

Chlorinated solvents are persistent chemicals, denser than water and tend to migrate through the saturated zones. Their migration may not be consistent with the general groundwater flow.

3.2.4 Metals

Owing to their limited mobility, metals do not present the same threat to groundwater and the quality of water resources as do solvents or oils, except where releases of metal salt solutions have occurred or where acidic materials have been co-disposed with metal-rich wastes. The movement of metals through the soil is significantly retarded by the presence of clay minerals and organic matter. The solubility of some metals, for example copper, zinc and lead, may increase under acidic conditions. 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 and arsenic may become more soluble at higher pHs. Wind can cause the dispersion of metal dusts.

3.2.5 Acids and alkalis

Acids and alkalis are highly mobile but are usually attenuated through dilution and chemical neutralisation during movement through soils. Acids may mobilise heavy metals and cyanide. Fluorides, nitrates, phosphates, sulphates and chlorides may also be leached from acidic or alkaline sludges by rainwater percolation or run-off.

3.2.6 Other factors

Building materials which are in contact with contaminated soils, for example concrete or bitumen and plastic coatings on buried pipes, may be weakened by chemical attack.

Mineral oil contamination may inhibit plant growth.

Where sites have experienced fires, the extent and nature of ground contamination can be significantly different due to the effects of hosing down, combustion and the creation of pyrolytic products.

Wind dispersion of contaminated soil may be a further transport mechanism where there is gross surface contamination by some of the less mobile contaminants, such as asbestos.

4. Sources of further information

4.1 Organisations

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

The Federation of British Electrotechnical and Allied Manufacturers' Associations (BEAMA)
8 Leicester Street
London
WC2 7BN

Institution of Electrical Engineers
Savoy Place
London
WC2R 0BL

Institution of Electronic and Radio Engineers
99 Gower Street
London
WC1E 6AZ

4.2 Sources of information concerning the activities described in this profile

Department of Trade and Industry, PA Consulting Group. *Cleaner technology in the United Kingdom.* London, HMSO, 1991.

Derry T K and Williams T I. *A short history of technology.* Oxford University Press, 1960.

Dunsheath P. *A short history of electrical engineering.* Faber and Faber, 1962.

Eduljee G H. *PCBs in the environment.* Chemistry in Britain, p242 - 244, 1988.

Erickson M D. *Analytical chemistry of PCBs.* London, Butterworth Publishers, 1986.

GEC Alstom Transformers. *Publication No. TF300 038850.* GEC Alstom, T&D, Stafford.

Health and Safety Commission. *Use of polychlorinated biphenyls in electrical apparatus.* Advice to Local Authorities. HSE, London, 1983.

Longland T, Hunt T W and Brecknell W A. *Power capacitor handbook.* London, Butterworth Publishers, 1984.

Moss S J and Ledwith A (Editors) *The chemistry of the semiconductor industry.* Blackie, 1987.

Polychlorinated biphenyls, PCBs hazard data bank sheet number 89. The Safety Practitioner 5, p28-29, 1987.

Quensen J F, Tiedje J M and Boyd S A. *Reductive dechlorination of polychlorinated biphenyls by anaerobic micro-organisms from sediments.* Science 242, p752-754, 1988.

Ridley F et al (Editors) *The electronics assembly handbook.* IFS Publication, 1988.

Royal Society of Chemistry. *Chemical safety data sheets. Volume 1. Solvents.* London, RSC, 1988.

Turner L W (Editor) *Electronics engineer's reference book.* 4th Edition. Butterworth Publishers, 1976.

Vincent C A, Bonino F, Lazzari M and Scrosati B. *Modern batteries an introduction to electrochemical power sources.* Edward Arnold, 1984.

Viney I and Bewley R J F. *Preliminary studies on the development of a microbiological treatment for polychlorinated biphenyls.* Archives of Environmental Contamination and Toxicology 19, p789-796, 1990.

Estimates of the size and geographical distribution of electrical and electronic manufacturing works can be obtained from the Central Government statistics, held principally by the Guildhall Library, Aldermanbury, London and the Business Library, 1 Brewers Hall Garden, London:

Census of Production Reports. Board of Trade, HMSO (from 1924 to 1969).

Business Monitor Series: Annual Census of Production Reports. Central Statistical Office, HMSO (from 1970 to date).

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

Engineering works: mechanical engineering and ordnance works
Metal manufacturing, refining and finishing works: electroplating and other metal finishing works
Metal manufacturing, refining and finishing works: lead works
Metal manufacturing, refining and finishing works: non-ferrous metal works (excluding lead 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.

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.

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

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

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

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

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. Of particular relevance is:

Department of the Environment. *Polychlorinated biphenyls*. Waste Management Paper No. 6. London, HMSO, 1994.

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.

The lists are categorised for convenience into generic industry and other sectors; these are not mutually exclusive. The groups are:

- A Electrical and electronic equipment
- B Printed circuit boards
- C Active electronic components
- D Transformers and capacitors
- E Insulated wires and cables
- F Batteries
- G Electric lighting
- H Other potential contaminants

A Electrical and electronic equipment

Principal raw materials and conductors	copper and copper alloys containing eg cadmium chromium silver beryllium aluminium lead tin
Other metals	iron nickel cobalt manganese
Insulation materials	asbestos bitumen polychlorinated biphenyls (PCBs)

B Printed circuit boards

Fire retardants	halogenated compounds combined with antimony oxides or alumina trihydrate zinc borate and other boron compounds ammonium polyphosphate combinations of phosphates and chlorides
Plating chemicals	copper salts tin-lead salts nickel salts tin
Photoresists	cinnamates and methyl methacrylates (co-polymerised with acrylate monomers and quinone) phenolic polymers diazonaphthaquinones
Etchants	ammonium bicarbonate ammonium chloride ammonium hydroxide ammonium phosphate chromium sulphate ferric chloride solution copper chloride solution fluoroboric acid
Cleaning agents	chlorinated/fluorinated organic solvents eg dichloromethane 1,1,1-trichloroethane trichloroethylene tetrachloroethylene trifluorotrichloroethane trichlorofluoroethane dichlorotetrafluoroethane alcohols eg methanol isopropanol aromatic solvents eg toluene n-butyl acetate sulphuric acid sodium perchlorate persulphates alkaline saponifiers detergents degreasing agents eg aqueous alkali or organic solvents resin removers eg sulphuric acid hydrochloric acid chromic acid fluorosulphonic acid alkaline permanganate solution (regenerated by adding persulphate)

Copper plating	pickling media eg sulphuric acid persulphates stannous chloride palladium chloride copper alkalis formalin complexing agents eg ammonium hydroxide stabilisers including sodium cyanide
Other metal plating	nickel (from acidic chloride, sulphate, fluoroborate or sulphamate baths) tin/nickel (from acidic chloride or ammonium bifluoride baths) tin (from fluoroborate baths)
Fluxes	alkyl acid phosphate
Flux removers	alcohols chlorinated/fluorinated hydrocarbons glycol ether

C Active electronic components

Conductors/semi-conductors	copper aluminium nickel titanium silver silicon germanium gallium arsenide indium phosphide zinc sulphide cadmium selenide
Fabrication processes	photoresists (polymers based on novolac resins and polyisoprene) etchants eg nitric acid hydrofluoric acid potassium hydroxide dopants eg boron arsenic phosphorous
Other process compounds	silicon tetrachloride trimethyl gallium

D Transformers and capacitors

Capacitor impregnates	PCBs polychlorinated naphthalene mineral oil dioctyl phthalate
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corrosion inhibitors eg mercury salts
chromate salts

mercury oxide
silver oxide
cadmium sulphate
iron sulphate
cadmium oxide
cadmium hydroxide
iron oxide

Electrode materials

zinc (plus alloys with lead or cadmium)
lead and lead alloys eg with antimony,
calcium or selenium
lead oxide
manganese dioxide
mercury oxide
silver oxide
acetylene black
bitumen
sulphur
barium sulphate
ligno-sulphuric acid derivatives
cadmium nitrate
nickel sulphate
nickel hydroxide
cobalt hydroxide
barium hydroxide
copper oxide
iron sulphide
thionyl chloride liquid
sulphuryl chloride liquid

G Electric lighting

Metals

tungsten
molybdenum
nickel
lead
tin
mercury

Electrodes and phosphors

magnesium tungstate
zinc silicate
zinc beryllium silicate
cadmium borate
yttrium vanadate (fluorescent phosphor)
barium carbonate
strontium carbonate

Polychlorinated biphenyls

H Other potential contaminants

The following may have been used in various manufacturing processes, including dielectrics:

Oils

minerals oils eg petroleum and coal tar derivatives (alkanes, cycloalkanes and aromatic hydrocarbons, with compounds of sulphur, oxygen and nitrogen)

synthetic oils eg polybutenes
fatty acid esters
silicone oils

cutting fluids
lubricating oils
hydraulic oils
oil additives

Asbestos

Table 1 Main groups of contaminants and their probable locations

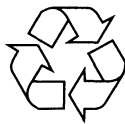
Engineering works: electrical and electronic equipment manufacturing works (including works manufacturing equipment containing PCBs)

Main groups of contaminants	Location														
	Raw materials delivery, storage and transfer	Process sector							Product storage/transfer	Waste/rejects storage	Waste disposal	Process pipework and pumps	Drainage system, including soakaways	Effluent treatment areas	Electricity transformer areas
		A	B	C	D	E	F	G							
Metals and metalloids	Shaded	Shaded	Shaded	Shaded											
Inorganic compounds	Shaded		Shaded												
Acids	Shaded		Shaded												
Alkalis	Shaded		Shaded												
Asbestos		Shaded													
Polychlorinated biphenyls (PCBs)	Shaded				Shaded										
Organic solvents	Shaded		Shaded		Shaded										
Halogenated compounds	Shaded		Shaded		Shaded										
Mineral oils	Shaded				Shaded										
Effluent treatment chemicals/sludges	Shaded		Shaded												

Notes:

- A. Electrical and electronic equipment
- B. Printed circuit boards
- C. Active electronic components
- D. Transformers and capacitors
- E. Insulated wires and cables
- F. Batteries
- G. Electric lighting equipment

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
Sewage works and sewage farms
Textile works and dye works
Timber products manufacturing works
Timber treatment works
Waste recycling, treatment and disposal sites: drum and tank cleaning and recycling plants
Waste recycling, treatment and disposal sites: hazardous waste treatment plants
Waste recycling, treatment and disposal sites: landfills and other waste treatment or waste disposal sites
Waste recycling, treatment and disposal sites: metal recycling sites
Waste recycling, treatment and disposal sites: solvent recovery works
Profile of miscellaneous industries incorporating:
Charcoal works
Dry-cleaners
Fibreglass and fibreglass resins manufacturing works
Glass manufacturing works
Photographic processing industry
Printing and bookbinding works

Copies may be purchased from:

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