

# **Metal manufacturing, refining and finishing works**

*non-ferrous metal works (excluding lead 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**

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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.

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

## **1. Background**

The following activities are dealt with in this profile:

Smelting	Production of metal from either ore (primary smelting) or from scrap (secondary smelting).
Refining	Usually by electrolysis or pyrometallurgically, to improve the purity of the metal obtained from smelting.
Foundry melting-out	Casting of the metal into ingots for further processing, or into shaped products by various techniques, including open or die-cast forging, rolling, continuous casting, machining, extrusion and the production of wrought metal shapes by hot or cold casting techniques.
Alloying	A metal with specific physical, chemical and mechanical characteristics prepared by adding, in the molten state, other metals or non-metals to a base metal. Almost all common engineering metallic materials are alloys.

The profile does not cover the extraction and concentration of metal ores for processing. The production of lead, iron and steel, and electroplating of metals are the subject of other Industry Profiles (see Section 4).

The metals included in this profile are:

- aluminium
- copper
- zinc
- nickel
- magnesium
- tin.

### **1.1 History**

Non-ferrous metal production in the United Kingdom pre-dates the Middle Ages; tin was extracted from Cornwall in Roman times, while lead and copper have been mined in Wales, Derbyshire and Cornwall for centuries.

The onset of the industrial revolution led to a rapid increase in the consumption of non-ferrous metals and by the mid-19th Century it became necessary for the industry in the United Kingdom to seek supplies of non-ferrous ores from overseas.

As the industry gradually expanded within the United Kingdom, scrap metal became available for re-smelting and a secondary smelting technology developed. Since the Second World War, ore-producing countries have tended to carry out primary smelting themselves and to export the product. These developments have led to the United Kingdom non-ferrous metal industry being less dependent on primary metals imports and using higher quality secondary metals. Today, primary smelting is only carried out to obtain aluminium and zinc.

In the last 20 years, while the overall quantity of metal produced and processed has not drastically changed, manufacture has been concentrated on fewer sites.

## **1.2 Location**

In the past, primary smelting works were built near to domestic sources of ore, and later, near to coalfields and ports. Ore was imported at places such as Liverpool, Widnes, Swansea, Newcastle and the Thames estuary. More recently, sites have also tended to be located near to cheaper sources of energy, for example near hydro-electric power stations in Scotland.

There are four primary aluminium smelters; two larger production units situated in Northumberland and Anglesey respectively and two smaller units operating in Scotland.

There are about twenty large secondary aluminium smelters in operation and many smaller ones. There are a number of aluminium foundries producing shaped castings. These vary in size from a furnace in a hanger to a fully automated plant. The aluminium not used for foundry applications is used mainly in extruded forms. Extrusion works, mostly situated in the Midlands, can vary in size; one company accounts for nearly half of the United Kingdom market.

Primary copper smelting is no longer carried out in the United Kingdom. In the past it was undertaken at sites in the Lake District and Cornwall, adjacent to sources of copper ore, and in South Wales, due to the proximity of coal which was used as a fuel for smelting. Secondary copper smelting is carried out at one site, in the West Midlands. Electrolytic refining took place on Merseyside until 1991.

Three large extruders of copper and copper alloys have melting facilities integrated with their extrusion plants; two of them are situated in the West Midlands and one in Staffordshire. In addition, two copper tube making plants have ancillary melting facilities. There are also a number of brass and bronze foundries mainly in the major industrial areas.

There is one large primary zinc smelter, treating imported concentrate and smelting lead and cadmium as by-products, near Avonmouth. Secondary zinc smelting is not carried out. There are a number of galvanising works, situated mainly in the West Midlands (see also the profile on electroplating and other metal finishing works, Section 4).

There is one nickel refining site, at Clyddach, South Wales. Nickel alloys are produced by clean technology processes such as inert gas or vacuum melting at sites mainly in Herefordshire.



Magnesium alloys are produced in ore works near Manchester and several magnesium foundries operate in various parts of the country. Aluminium/magnesium alloying foundries are often found at the same locations.

There are no operational primary tin smelters in the United Kingdom. In the past, a great deal of tin smelting took place in Cornwall, in small units close to the mines producing ore. Tin-containing residues were treated in two smelters situated on Merseyside and Humberside which closed in the 1970s and late 1980s respectively. The only surviving tin producing plant is a secondary smelting facility in South London, recovering tin from spent solder alloys. There are a few foundries manufacturing bronze castings and tin alloy solder and a major manufacturer of tinned steel plate in South Wales.

## **2. Production processes**

### **2.1 Raw materials and delivery**

The main raw materials include:

- metal ores
- smelted and refined base metals
- cast or billeted metals
- fuels (gas, oil, coke, diesel, petrol)
- fluxes
- anthracite or carbon used for smelting or for electrode manufacture in electrolytic refining
- acids and alkalis for some electrolytic processes
- master alloys for alloying
- quenching fluids.

Process-related materials include:

- maintenance and cutting oils
- acids and alkalis for water treatment and neutralisation of wastes
- degreasing solvents
- chemicals for finishing processes eg brightening.

Some works may store liquefied flammable gases and oxygen for use as burner fuels for smelting, and nitrogen for creating inert atmospheres during certain stages of production.

The majority of process and process-related raw materials received on site arrive by either rail or road in bulk quantities. Materials such as cooling water treatment chemicals, foundry sand additives and maintenance oils may be received in smaller quantities, typically by road transport. Burner fuel for smelting and similar heating operations can be delivered by bulk tanker in liquid form or by direct pipeline. Acids, alkalis and solvents are typically delivered by bulk road tanker, with other minor chemicals being delivered in drums, kegs and intermediate bulk containers (IBCs). Nitrogen and natural gas may also be delivered direct via a pipeline from a third party supplier.

## 2.2 Transfer of materials on site

Solid metal is normally transferred around the site using fork-lift trucks, whereas liquids are typically transferred by pumping to the area of storage or final use. Drums and kegs may be either manually or mechanically handled, whereas the larger IBCs are transferred by fork-lift truck.

Bulk carbon material used in primary smelting is typically transferred using conveyor belt systems or other mechanical equipment. Within the smelting and production facilities, the handling of raw materials is by a mixture of manual, semi-automatic and automatic operations, involving lifting gear, fork-lift trucks and conveyor systems.

Refined metal and metals to be alloyed are very often transported in the molten state prior to production of the final alloy. Smelting and roasting operations may produce slag or dross which is removed from the molten material either manually or automatically.

Cutting oils and degreasing solvents are usually stored in drums or bulk containers and are either pumped or transferred by fork-lift truck to the place of use.

## 2.3 Aluminium

### 2.3.1 Primary aluminium smelting

In the United Kingdom, all aluminium is produced by the electrolytic reduction of alumina dissolved in a molten cryolite (sodium aluminium fluoride)-based bath, at a temperature of approximately 960°C. The electrolysis cell consists of a carbon cathode, insulated by refractory bricks inside a rectangular steel shell, and carbon anodes. The cells are connected in series and direct current passes from the anode, through the molten bath, to the cathode and then to the next cell. The anodes are made in situ from a paste of calcined petroleum coke and coal tar pitch which is either pre-baked or baked by the heat rising from the bath. Since the anode is gradually consumed, anode stubs require replacing regularly. They are usually recycled through the anode plant. Cathodes are not consumed but will need replacing every 6-8 years. The cathode residue is known as spent pot lining and may contain sodium cyanide. This is produced by reaction between nitrogen compounds, present in the anthracite used to manufacture the cathodes, and sodium compounds and is absorbed during electrolysis.

Compounds produced during smelting include gaseous fluoride compounds, tar, carbon black, carbon oxides and sulphur dioxide. In addition, significant quantities of particulate fluorides and alumina are discharged into the atmosphere.

Fumes are removed by a combination of electrostatic precipitation and wet scrubbing with an alkaline liquor.

### 2.3.2 Secondary aluminium smelting

Scrap aluminium is sorted, magnetically separated from ferrous materials, de-oiled, de-coated and compacted in a baling press.

Aluminium swarf is dried and de-oiled in an externally heated rotating drum; evaporated oil and water are combusted in a secondary combustion chamber. Paint or plastic coatings are removed by passing fragmented scrap through an oven or mesh conveyor and circulating hot gases to volatilise or burn off the

coatings. Foil-backed scrap paper is shredded and milled and the paper removed by controlled combustion in a rotary furnace. Multi-metal components such as car engines may be melted in a fuel-fired sloping hearth furnace, where molten aluminium runs into a collecting trough and solid iron remains in the hearth.

Feed materials are blended to suit the required product composition and melted in furnaces with capacities in the range 1-50 tonnes. Fluxes, typically sodium and potassium chloride with some fluoride, may be used to assist melting and reduce metal losses.

By-products of secondary smelting are mainly air emissions; black smoke from the burning of oily swarf, salt fumes arising from the chloride-containing fluxes, and aluminium and magnesium chloride fumes, from magnesium impurities, which readily hydrolyse to produce hydrogen chloride. Emissions are generally contained by modern filtering systems.

### *2.3.3 Aluminium refining, casting, alloys*

Before casting, molten aluminium may be refined to remove sodium, calcium, magnesium and hydrogen, by the injection of chlorine or a mixture of chlorine with argon or nitrogen. To combat the problem of the emission of unreacted chlorine gas, large-scale facilities have recently adopted the procedure of adding hexachlorine tablets to the mixture of molten aluminium and argon or nitrogen and then washing the flux with water. The aluminium may be degassed to remove dissolved hydrogen by the injection of argon or nitrogen and filtered through a bed filter and/or ceramic mesh to remove dross or other foreign matter.

Alloying elements are added as ingots, rods, molten metal from an induction furnace or metal salts (if only small quantities are used).

Slabs and billets are cast using fixed, water-cooled metal moulds.

Dross, consisting mainly of aluminium metal alloy and aluminium oxide, is recycled via a ball mill for further metal recovery. The product of this process is about 70% aluminium.

Drosses must be stored in dry conditions to prevent them absorbing moisture and releasing acidic fumes or hydrogen.

The most widely used casting processes used are casting in temporary moulds (natural or resin-bonded sand moulds) and die-casting using a permanent shell die.

Aluminium is extensively used in engineering components, vehicle body parts, food and drink cans, cooking utensils, foil sheeting and the building industry.

## **2.4 Copper**

Primary smelting is no longer carried out in the United Kingdom. However, smelting was carried out in the past and involved roasting the ore to remove sulphur, followed by reducing the resultant oxide with coal in a furnace to produce the raw metal.

#### 2.4.1 Secondary copper smelting

Secondary smelting produces copper of sufficient purity for electrolytic refining. Scrap copper may be hand sorted and de-oiled; iron material is separated magnetically from the copper before smelting.

Lower grades of scrap (ie up to about 30% copper) are smelted in a blast furnace. Smelting reduces the copper oxide to liquid copper by reaction with carbon monoxide and iron, which forms iron oxide. The iron oxide reacts with silica in the charge to form a molten slag which is granulated in water, dried, graded and sold as shot blast grit. The molten copper, known as 'black copper' (80% copper), is transferred molten to the converter furnace.

Impurities in the black copper are removed by oxidation refining in the converter, using silica and blown air. Iron-rich slag returns to the blast furnace, whilst the tin-rich slag is sold to a tin refiner. The molten metal (96% copper) is transferred to an anode furnace for electrolytic refining.

Mixed scraps (50% copper) are smelted in a reverberatory furnace. Smelting is achieved by the reduction of copper oxide to metal from reaction with iron in the charge. A silicate slag forms a separate layer above the molten metal, impurities are removed by blowing with air and zinc oxide is collected as dust. After refining to 98% copper, the molten metal is transferred to an anode furnace for electrolytic refining.

Metal transferred from the converter and reverberatory furnaces (containing up to 1% oxygen) is mixed with recycled blister copper (another type of rough copper) or recycled anode from the electrolytic refinery tank house. Excess oxygen is removed by injecting with natural gas. The anode metal (99.2% copper) is then cast in a continuous strip and cut to size.

#### 2.4.2 Electrolytic copper refining

The cell used for the electrolytic refining of copper consists of copper anode slabs suspended in an electrolyte of copper sulphate and sulphuric acid. A thin sheet of pure copper is suspended between each anode to form the cathode. When current is passed through the cell, the anode is gradually consumed while copper deposits on the cathode (99.99% copper). Anode sludge contains small quantities of precious metals and nickel sulphate which are recovered by evaporation under vacuum.

#### 2.4.3 Copper and copper alloys

The products of the copper and copper alloy manufacturing sector include:

- continuous cast wire rod
- slabs (plate, sheet, strip)
- billet (rod, bar, hollow sections and tubes)
- ingot (shapes, sand castings, die castings)
- foundry products.

The main alloys are brasses (copper-zinc alloy), bronzes (copper-tin alloy) and cupro-nickels (copper-nickel alloy).

Copper wire rod, for wire drawing, is produced from copper cathodes by continuous melting, casting and rolling processes.

Slabs and billets are produced by melting copper and copper alloys in channel induction furnaces and coreless induction furnaces and then continuous, or semi-continuous horizontal or vertical casting. This is followed by extrusion, drawing or rolling.

Copper alloy ingots are cast after melting clean material (ie cathode and clean scrap) in coreless induction furnaces, or dirty material (swarf and mixed alloy scrap) in reverberatory or rotary furnaces.

Foundry products are produced in small quantities in electric induction furnaces and sand moulds. Only a small proportion of copper alloy castings in the United Kingdom are produced by die casting.

Significant quantities of zinc oxide, often contaminated with lead and other metals, are produced and must be periodically removed from the filter plant. Various attempts have been made to recycle this zinc oxide but their commercial success remains doubtful. It is usually disposed of as a controlled waste.

Copper has many uses, for example in a wide range of engineering and electrical components, wiring, pipework, sheeting for cladding in building construction and in boats.

## **2.5 Zinc**

### *2.5.1 Zinc smelting and refining*

Historically, zinc was produced by distillation and condensation using the retort process. One such facility existed in the West Midlands but it closed several decades ago.

The only primary smelter operating in the United Kingdom uses the Imperial Smelting Furnace Process. Zinc ore concentrate is crushed and sintered (desulphurised and pelletised). The sulphur is recovered as sulphuric acid; cadmium and mercury are also recovered. The sinter is crushed and screened to the correct size for the blast furnace. Pre-heated air injected into the furnace reacts with coke to produce carbon monoxide and melts the charge to form slag. The carbon monoxide reduces the metal oxides in the bottom of the furnace to produce lead and zinc metal. The zinc metal is volatile at the operating temperatures and leaves the furnace with gases which also contain some cadmium and lead. They enter a splash condenser in which a shower of molten lead quenches the gases and the zinc, together with other metal impurities, is absorbed on to the liquid lead. The resulting alloy is cooled and the zinc metal floats to the surface where it is collected for refining.

Lead and cadmium are recovered as by-products of the process (see the profile on lead manufacturing works, Section 4). Dross, containing lead, arsenic and cadmium, is returned to the blast furnace.

Zinc obtained by primary smelting contains varying amounts of cadmium, lead, copper, arsenic, antimony and iron. It is refined by reflux distillation using natural gas as heating fuel. Molten zinc is fed into a column where the cadmium and a high proportion of the zinc is distilled. The mixture is condensed and fed to a second column operating at a slightly lower temperature which distils the remaining cadmium, condensed as a zinc-cadmium alloy, which is transferred to a cadmium

refinery. The metal run-off from the bottom of the second column is high grade zinc (99.99% purity).

The zinc is treated with sodium to remove residual arsenic, antimony and copper to produce a lower grade zinc, used mainly for galvanising.

Zinc dross can contain minor quantities of arsenic; this can be released as arsine when zinc scrap or dross containing arsenic is exposed to strong acids.

### *2.5.2 Galvanising*

The main use for zinc in the United Kingdom is as a coating for protecting steel from atmospheric corrosion (galvanising). Zinc can be applied either by electrodeposition or by immersion into a liquid zinc alloy bath (hot-dip galvanising). At a hot-dip galvanising works, the entrapped zinc is drained from large steel components before they are cooled. Large numbers of smaller components may be immersed in the bath in a basher, from which the zinc is drained after it is withdrawn. For more information on galvanising, see the profile on electroplating (Section 4).

### *2.5.3 Zinc casting and alloying*

Melting and alloying are usually carried out in indirectly fired crucible furnaces (gas or oil heated). Alloy additions are usually solids but molten aluminium may be added in certain processes. Fluxes are needed to absorb impurities. The standard flux contains zinc chloride, magnesium chloride and sodium silico-fluoride. Gaseous silicon tetrafluoride is produced and removed by wet scrubbing.

The metal is usually cast into permanent moulds of cast iron; continuous casting machines are used to produce rod for reduction to wire.

## **2.6 Nickel**

The only nickel refining operation in the United Kingdom uses the carbonyl process. The nickel-rich concentrate is heated in a stream of hydrogen and carbon monoxide to form nickel carbonyl particles which decompose into elemental nickel and carbon monoxide. Carbon monoxide and hydrogen are recovered and recycled. Waste gases containing carbon monoxide, nickel carbonyl and nickel oxide are fed into an incinerator, where the residual nickel carbonyl is converted to nickel oxide and carbon dioxide. The process requires the on-site generation of hydrogen, carbon monoxide and carbon dioxide.

Recycling of fully identified and segregated scrap is carried out by re-melting with the feedstock or by arc furnace melting and argon-oxygen-decarburisation. Nickel-cobalt alloys are melted in an induction furnace. There are various types of casting methods used, including air casting, vacuum casting, vacuum arc re-melting, electroslag re-melting and investment casting.

Nickel is used in pure form in the chemical industry but its main use is in the production of nickel compounds for electroplating applications, nickel-containing alloys, such as stainless steels, and cupro-nickels.

## **2.7 Magnesium**

Magnesium was produced during the Second World War by electrolysis of sea water at a plant situated on the North East coast. This closed when more economic sources of magnesium were developed overseas in countries with cheap electricity. There is a major producer of magnesium alloys in Lancashire.

Magnesium alloys are used in aerospace and automotive applications in wrought form or as castings.

## **2.8 Tin**

There is now no primary smelting of tin in the United Kingdom and the only processes carried out today are secondary smelting, refining and alloy production.

Metallic scrap and metal-rich drosses are melted in kettles which are indirectly heated by oil, gas or electricity. Material with high dross or flux content is melted in sloping hearth reverberatory furnaces or rotary furnaces. During melting, oxides and residual fluxes float to the surface and are removed.

The tin is refined pyrometallurgically by lowering the temperature in the kettle or furnace to precipitate high melting point impurities, such as iron or copper, which collect on the surface and are removed. Chemicals used to remove impurities include sulphur, to remove residual copper as the sulphide, and ammonium chloride, to remove zinc as the chloride. The resultant drosses are sold for recovery of their metals. Sodium carbonate is added to take up any residual metals.

Tin is electrolytically refined using anodes of crude solder and cathodes comprising thin sheets of refined solder in an electrolyte of hydrofluorosilicic acid or hydrofluoroboric acid. Tin and lead are re-deposited on the cathode and impurities remain on the anode as slime. Periodically, cathodes are washed and melted, and anodes brushed, washed and the slime filtered. All metallic process waste is sold for recovery.

The main uses for tin are the manufacture of solder alloys, in electronic micro-circuitry, as a coating for steel in tin plate and as a constituent of bronze.

## **2.9 Nature and transfer of finished products**

Most material is transferred in the solid state. However, it is common to transport liquid aluminium from a melting facility in one location to another situated within a reasonable distance in specially designed refractory-lined road tankers.

The output from secondary copper or aluminium smelters and primary zinc smelting is normally a commercial grade of these metals in standard forms. They are usually stored on site or in a bonded warehouse and transferred by road.

Extruded materials are sawn into smaller lengths to obtain manageable parts. They are then normally packed to protect their surface appearance during delivery.

Rolled material is usually delivered in coil form to the customer and despatched by road.

## **2.10 Ancillary activities**

Many works have their own electricity substations, particularly if electric furnaces are used, and these may have contained polychlorinated biphenyl (PCB) oils in transformers and/or capacitors.

There are likely to be on-site storage and distribution systems for fuel oil or liquid gas for smelting and drying operations. Larger works may include on-site steam and power generation plant, and water purification and wastewater treatment plants, all of which may involve the storage and use of a wide variety of chemicals including acids and alkalis. In addition, sites may have underground storage tanks that may have contained materials such as petrol, diesel, liquid wastes and fuel oil.

Most works have extensive lagging of pipes, vessels etc. Asbestos may have been used as lagging material and also for cladding or roofing of buildings.

## **2.11 Waste management**

Environmental legislation has led to the adoption of effective waste management policies in modern plant, but not so much care may have been taken with waste in the past. The modern treatment of waste is dictated by such factors as the quantities produced, their suitability for recycling and the hazard they represent.

The amount of metal waste requiring disposal has decreased over the last few decades as recycling has become more widely practised and improvements in process operations have reduced the quantity of waste per tonne of metal produced.

It is the usual practice for works producing moderate quantities of waste to store them in banded sites within the works until there is sufficient for cost effective disposal to landfill or for recycling.

Hazardous wastes containing metals and metalloids, such as cadmium and arsenic, are stored in water and airtight drums and sent for disposal at appropriately licensed sites.

Less hazardous wastes which cannot be recycled are disposed of to licensed waste disposal sites.

Works producing large amounts of heavy metal dust have a wash down policy to ensure that dust containing metal is not blown into the surrounding environment. The washdown water is generally treated before discharge to the foul sewer or rivers. In the past it may have been disposed of untreated.

## **3. Contamination**

The contaminants on a site will largely depend on the history of the site and on the range processes carried out 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.



For contaminants resulting from electroplating and metal finishing, including anodising, see the relevant profile (Section 4).

### **3.1 Factors affecting contamination**

The types and quantities of chemicals used, and the contaminants that may be produced, are largely dependent upon the size of the operations at an individual site and the types of metals and alloys refined and processed.

The most likely causes of contamination are spillage or leakage of materials such as fuels and oils, solvents (degreasing agents), alloying materials, powdered or molten metals. This could occur around storage or process areas or where leaks occur in pipework.

Chemicals which may contaminate storage and processing areas include those involved in casting operations (eg cold curing organic resins), indirect cooling water systems (particularly acids and alkalis) and surface treating and quenching operations.

Most modern metal/alloy production sites have equipment to reduce metallic atmospheric emissions. Consequently any metal contamination is probably localised in spent refractory and slag/dross waste storage areas. At older facilities, fall-out from stack emissions may have occurred within the site or close to its boundary. The area and type of fall-out depends on stack size and dispersion factors.

There may be contamination by polychlorinated biphenyls (PCBs) associated with former transformer areas.

Decommissioning of buildings or pipework containing asbestos materials may have resulted in their dispersal across the site or disposal in on-site landfills.

### **3.2 Migration and persistence of contaminants**

#### **3.2.1 *Metals and inorganic compounds***

The highest concentrations of heavy metals are likely to be found near to the surface, and a general fall-off in concentration with depth would be expected. The metalloids and carbon are also likely to be largely restricted to the surface layers of soil.

Contamination may arise from the storage and handling of metal ores. Oxidation of sulphide ores produces metal-rich, acidic leachate.

Metals released from the processes carried out on site have varying degrees of solubility depending upon the nature of the associated anion; the oxides and sulphides in many cases are of low solubility and the concentration gradient through the soil is likely to show a steep decline with depth.

Water softeners and additives have varying water solubilities; downward leaching of contamination from these sources could potentially be significant.

The transport and fate of metal compounds through the soil depends on physical, chemical and biological factors. The greater the natural organic matter and clay

content in the soil, the greater the degree of adsorption of contaminants and the lower their potential for migration. Thus the greatest degree of migration will occur in coarse-grained sands and gravels with little organic matter. The less soluble compounds which become adsorbed on to clay or organic matter will continue to desorb in soil-water, providing ongoing sources of water pollution long after the source has been removed.

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 pH levels. Thus, under acid or alkaline conditions, metal compounds may contaminate surface and groundwater as a result of leaching and rainwater run-off from surface deposits.

### *3.2.2 Organic compounds*

The organic solvents (for example cleaning and degreasing agents) and fuel oils likely to be encountered are volatile and have moderate to high vapour pressures and may migrate through unsaturated soil as vapours. If vapours accumulate in poorly ventilated, confined spaces such as drains, they can present a fire or explosion hazard.

Relatively small amounts of oils and solvents pose a considerable threat to water resources, both through surface run-off and groundwater infiltration. Once spilled into the ground, these fluids may migrate. As with metals, the transport and fate of organic compounds within the sub-surface environment is dependent upon physical, chemical and biological factors.

Non-chlorinated oils and solvents are mostly less dense than water and the non-soluble components float on top of the water table.

Chlorinated solvents can contaminate drinking water at very low concentrations. They are generally more dense than water and tend to migrate to the bottom of aquifers, sometimes in the opposite direction to the general groundwater flow. Chlorinated solvents are persistent, they degrade slowly and only under specific conditions.

Contamination by organic solvents may result in groundwater contamination by other organic materials which have low solubilities in water but are readily soluble in solvents.

Biodegradation processes in soils can be influenced by a number of factors, mainly moisture content, oxygen concentration and pH. For example, low moisture content reduces microbial 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.

### 3.2.3 Other factors

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

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

## 4. Sources of further information

### 4.1 Organisations

For information concerning the non-ferrous metal processing and refining industry in the United Kingdom, the following organisations should be consulted:

The Aluminium Federation  
Broadway House  
Calthorpe Road  
Birmingham  
B15 1TN

Association of Bronze and Brass Foundries  
136 Hagley Road  
Birmingham  
B16 9PN

The British Non-Ferrous Metals Federation  
10 Greenfield Crescent  
Birmingham  
B15 3AU

The Institute of Materials  
1 Carlton House Terrace  
London  
SW1Y 5DB

The Institute of Metal Finishing  
48 Holloway Head  
Birmingham  
B1 1NQ

The Institution of Mining and Metallurgy  
44 Portland Place  
London  
W1N 4BR

Nickel Development Institute  
European Technical Information Centre  
The Holloway  
Alvechurch  
Birmingham  
B48 7QB

Zinc Development Association  
42-46 Weymouth Street  
London  
W1N 3LQ

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

**Alexander W and Street A.** *Metals in the service of man*. London, Penguin, 1989.

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

**Higgins R A.** *Properties of engineering materials*. Sevenoaks, Hodder and Stoughton, 1980.

**Perry R H and Chilton, C H.** *Chemical engineers handbook*. 5th Edition. London, McGraw-Hill, 1973.

**Robb C.** *Metals databook*. London, Institute of Metals, 1987.

**Ryan W (Editor).** *Non ferrous extractive metallurgy in the United Kingdom*. London, Institution of Mining and Metallurgy, 1968.

Case study including information relevant to this Industry Profile:

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

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

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

## 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. Of particular relevance are:

**Her Majesty's Inspectorate of Pollution.** *Processes for the manufacture of zinc*. Chief Inspector's Guidance to Inspectors. Process Guidance Note IPR 2/4. London, HMSO, 1994.

**Her Majesty's Inspectorate of Pollution.** *Processes for the production of refractory metals*. Chief Inspector's Guidance to Inspectors. Process Guidance Note IPR 2/6. London, HMSO, 1994.

**Her Majesty's Inspectorate of Pollution.** *Processes for the manufacture of magnesium and titanium*. Chief Inspector's Guidance to Inspectors. Process Guidance Note IPR 2/7. London, HMSO, 1994.

**Her Majesty's Inspectorate of Pollution.** *Processes for the production of aluminium*. Chief Inspector's Guidance to Inspectors. Process Guidance Note IPR 2/8. London, HMSO, 1994.

**Her Majesty's Inspectorate of Pollution.** *Processes for the production of copper and copper alloys*. Chief Inspector's Guidance to Inspectors. Process Guidance Note IPR 2/9. London, HMSO, 1994.

**Her Majesty's Inspectorate of Pollution.** *Nickel production and the processing of cobalt and nickel alloys*. Chief Inspector's Guidance to Inspectors. Process Guidance Note IPR 2/11. London, HMSO, 1994.

**Her Majesty's Inspectorate of Pollution.** *Tin and bismuth processes*. Chief Inspector's Guidance to Inspectors. Process Guidance Note IPR 2/12. London, HMSO, 1994.

**Her Majesty's Inspectorate of Pollution.** *Processes for the production, melting and recovery of cadmium, mercury and their alloys*. Chief Inspector's Guidance to Inspectors. Process Guidance Note IPR 2/13. London, HMSO, 1994.

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:

**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.

**Verschueren 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. A current list of titles in this series is

available from HMSO Publications Centre, PO Box 276, London, SW8 5DT. Of particular relevance is:

**Department of the Environment.** *Special waste: A technical memorandum providing guidance on their definition.* Waste Management Paper No 23, London, HMSO, 1981. New edition in preparation.

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.

### **Raw materials (including those used in alloying) and processing by-products**

Metals and metalloids	aluminium antimony arsenic bismuth boron cadmium chromium copper lead magnesium manganese mercury (metal and oxides as pigments) molybdenum nickel niobium platinum silver tantalum tin titanium tungsten vanadium zinc
Carbon	charcoal anthracite
Inorganic compounds	boric oxide chlorides chrome oxides fluorides sulphides sulphates
Acids	sulphuric hydrochloric
Alkalis	see Cleaning agents
Organic solvents	see Cleaning agents

## Quenching agents

Salt baths

cyanides  
chlorides  
nitrates  
nitrites

## Cleaning agents

Alkaline (sodium salts)

phosphate  
hydroxide  
silicates  
carbonates  
borates

Mineral acids

hydrochloric  
orthophosphoric  
sulphuric  
hydrofluoric  
nitric

Other inorganic compounds

ammonium persulphate  
sodium bisulphate

Halogenated solvents

dichloromethane  
tetrachloroethane  
trichloroethylene  
1,1,1-trichloroethane  
trichlorotrifluoroethane

Non-halogenated solvents

ethanol  
isopropanol  
methanol  
benzene  
toluene  
ethylene glycol  
glycol ethers  
petroleum fractions (kerosene, naphthas)

Other organic compounds

oxalic acid  
amines

## General contaminants

Fuels

coke/coal  
oil

Polychlorinated biphenyls (PCBs)

Asbestos



**Table 1 Main groups of contaminants and their probable locations**

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

Contaminants			Location												
			Raw materials storage	Refining, processing alloying areas						Shaping, working and finishing areas	Building fabric/ pipework	Waste storage areas	Drains, sumps and tanks	Transformers/ switchgear	
				Aluminium	Copper	Zinc	Nickel	Magnesium	Tin						
Main groups	Sub-groups	Alkalis													
		Mineral acids													
		Organic acids													
		Oil/fuels													
		Organic solvents													
Metals	Aluminium														
	Copper														
	Zinc														
	Nickel														
	Magnesium														
	Tin														
Other metals and metalloids¹			2								3				
Other inorganic compounds⁴															
Asbestos															
Polychlorinated biphenyls (PCBs)															

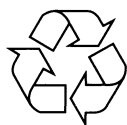
1 Antimony, arsenic, bismuth, boron, cadmium, chromium, lead, manganese, mercury, molybdenum, nickel, niobium, platinum, silver, tantalum, titanium, tungsten and vanadium

2 Magnesium, lead and titanium

3 Antimony and lead

4 Derived from chlorine, sulphur, nitrogen, boron or phosphorus

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:

**Publications Sales Unit  
Block 3, Spur 7,  
Government Buildings,  
Lime Grove,  
Ruislip, HA4 8SF**

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