

**Department for  
Environment Food and  
Rural Affairs**

**Profile of land uses  
which may have been  
subject to radiological  
contamination**

Draft for Consultation

April 2004

Entec UK Limited



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**Report for**

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# Department for Environment Food and Rural Affairs

## Profile of land uses which may have been subject to radiological contamination

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April 2004

Entec UK Limited



Certificate No. EMS 69090



Certificate No. FS 13881

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# Foreword

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The purpose of the publication is to provide regulators, developers, consultants and other interested parties with authoritative and researched advice on the likely occurrence of radiological ground contamination in the UK as a result of certain industrial practices. The publications cannot address the specific circumstances of each site, since every site is unique. Anyone using the information in this publication must, therefore, make appropriate and specific assessments of any particular site or group of sites. Neither the Department nor 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.

## Acknowledgements

The Department for Environment, Food and Rural Affairs would like to thank...



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# 1. Introduction

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## 1.1 Purpose of the Profile

Industry Profiles provide developers, regulators (including the Environment Agency and local authorities), consultants and anyone else interested in land contamination, with information on the processes, materials and wastes associated with individual industries or generic types of land use. They are not definitive studies but introduce some of the technical considerations that need to be borne in mind at the start of an investigation for possible chemical or radiological contamination. A number of industry profiles were published in the 1990s for land-uses which could have resulted in the chemical contamination of land.

Whilst most of the existing profiles give information on the contamination which might be associated with specific industries, this profile has concentrated on land uses where a specific form of contamination – that associated with radioactive substances, may have occurred. This profile deals with all forms of such contamination except that arising from Licensed Nuclear Sites.

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 or landuse;
- 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 that are no longer followed, and may omit current practices which avoid contamination.

Information on likely contamination of the ground is a fundamental prerequisite of designing an intrusive site investigation, and such information is normally assembled through a desk study. Industry Profiles are an invaluable tool in producing desk studies and formulating Conceptual Models (the basis of undertaking a risk assessment for the site) to satisfy both private sector and regulatory requirements.

## 1.2 Description of Regulatory Interfaces

A number of areas of legislation deal with different aspects of contamination in the environment. Two specific areas of legislation deal with radioactivity, and these are briefly described below, followed by a summary of wider relevant legislation. The reader is referred to the original legislation for a more detailed understanding of each regime.

### **Radioactive Substances Act (1993)**

The primary aim of the Act is to ensure the control of radiation exposure resulting from radioactive wastes entering the environment through the application of a prior permission

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regime. Because radioactive wastes are potentially harmful it is important not only that they are disposed of safely by appropriate routes, but also that they are not produced in unnecessary quantities. For this reason the Act controls the use of radioactive materials as well as the wastes themselves. The objective of regulating the use of radioactive substances and the management of radioactive wastes is to protect man and the environment.

The Act requires the registration of premises where radioactive materials are kept or used and in normal circumstances it is an offence to possess such materials other than in accordance with a registration under the Act. The Act also requires prior authorisation for the accumulation and disposal of radioactive waste.

Exemption orders are statutory instruments made under the Act and specify classes of premises, undertakings or persons, and radioactive material or radioactive apparatus which do not need to be registered or further authorised. They apply to all sectors using radioactive material, nuclear and non-nuclear. The nature of the material or the conditions of use are such that the protection of the public and the environment can be assured.

The detailed arrangements for control are contained in certificates of registration and authorisation in respect of particular premises, or in exemption orders. Premises are inspected to check that the certificate conditions are complied with.

The Act is administered by the Environment Agency in England and Wales and the Scottish Environment Protection Agency in Scotland.

### **Ionising Radiation Regulations (1999)**

The protection of persons working with radioactive materials is covered by the The Ionising Radiations Regulations 1999 (SI 1999 No 3232), made under the Health and Safety at Work etc Act 1974, and administered by the Health and Safety Executive. The main aim of the regulations and supporting Approved Code of Practice is to establish a framework for ensuring that exposure to ionising radiation arising from work activities, whether from man-made or natural radiation and from external radiation (eg X-ray set) or internal radiation (eg inhalation of a radioactive substance), is kept as low as reasonably practicable and does not exceed dose limits specified for individuals.

### **Part IIA of the Environmental Protection Act (1990), the Contaminated Land Regime**

The Part IIA Contaminated Land Regime was introduced in April 2000 to deal with the historical legacy of land contamination in the UK. It places a duty on each Local Authority to inspect its area to identify contaminated land meeting the definition set out in the Act and associated statutory guidance, and to secure remediation of that land in accordance with the primary legislation and supporting statutory guidance. Part IIA is concerned only with the current condition and use of the land at the time of any inspection, but may only be applied where other control mechanisms (such as Waste Management Licensing or Pollution Prevention and Control Regulations) are not applicable. For sites where development or a change of use under the requirements of Town and Country Planning legislation is proposed, remediation of ground contamination can be achieved through the planning process without the application of Part IIA.

For land to be determined contaminated land, there must be a significant pollutant linkage – a contaminant must exist in, on or under the land which is linked by a viable pathway to a defined receptor, and the receptor must be exposed to or affected by the contaminant with the potential to cause harm or pollution. The primary legislation excluded harm or pollution attributable to

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any radioactivity possessed by a substance from the regime introduced in England in April 2000, but provided for new regulations or changes in existing legislation to be made in the future to deal with radioactive contamination.

### **Town and Country Planning Act (1990)**

Land contamination, or the possibility of it, is a material planning consideration for the purposes of town and country planning. The Local Planning Authority will issue planning consents under the Town and Country Planning Act (1990) subject to conditions which are likely to be agreed with the Environment Agency and the HSE in relation to dealing with any form of contamination in, on or under the land, including radioactivity. Under the suitable for use approach, risks should be assessed, and remediation requirements set, on the basis of both the current use and circumstances of the land and its proposed new use (DETR Circular 02/2000).

### **Pollution Prevention and Control regime**

The Integrated Pollution Prevention and Control (IPPC) regime has introduced measures designed to prevent, or where this is not practicable, to reduce emissions to air, land and water from prescribed industrial activities, including measures concerning waste. All industries covered by the regime are required to apply for new permits which cover their operations. As a part of the permitting process, the condition of the site must be defined as a baseline for future operation, and this is done by undertaking desk-based, and sometimes intrusive investigations. Radioactive contamination is considered alongside chemical contamination of land and water.

## **1.3 Radioactivity**

Radioactivity is a property possessed by isotopes and some elements of spontaneously emitting energetic particles and energy rays from the disintegration of their atomic nuclei. The property is harnessed in many industries but can also present a number of risks to human health and the general environment.

### **1.3.1 Basic structure of matter**

Atoms are the simplest unit into which matter can be broken down, whilst still retaining its unique identity and properties. The atom itself is made up from a number of fundamental particles; at the centre of the atom is the nucleus, which consists of tightly bound protons and neutrons, orbiting around which are smaller light weight particles called electrons.

These particles combine in differing proportions to form atoms. As each of these combinations will give an atom different properties, they are divided into elemental groups, with the number of protons in the nucleus determining the element of the atom. The number of protons in the nucleus of an element is called the atomic number, while the number of protons and neutrons added together is defined as the mass number.

### **1.3.2 Radioactivity and Radiation**

The atoms of a specific element have to contain the same number of protons, but can have different numbers of neutrons; atoms of an element that have different numbers of neutrons are called isotopes of that element.

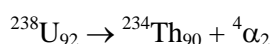
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An atom will only be stable if the nucleus contains a specific number of neutrons (which differs for each element). An unstable atom will try and reach a stable state by emitting energy in the form of radiation, this process is defined as decay and can result in an atom changing to become a different element. A decaying atom may form a number of radioactive isotopes of different elements until it reaches a stable state, which is often referred to as a decay chain.

There are a number of ways in which a radioactive atom can decay, resulting in the production of ionising radiation, these are described below:

### **Alpha Particles ( $\alpha$ )**

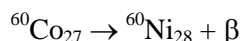
Alpha particles are emitted from heavy nuclei containing a large number of neutrons and protons, such as uranium isotopes. Alpha particles consist of two neutrons and two protons bound together, which behave as a single particle. An example of alpha decay is as follows:



As alpha particles are relatively massive, with two positive charges, they interact readily with the material that they pass through. Due to this alpha particles have a very short range, only being able to travel a few centimetres through air and are easily stopped by a thin sheet of material such as paper.

### **Beta Particles ( $\beta$ )**

These are high speed electrons that are emitted from the nucleus of an atom. An example of beta decay is as follows:



During the beta decay the atomic number is increased by one, thus changing the element. The increase in the atomic number is from the creation of another proton within the nucleus, in this process a neutron is changed to a proton and an electron, the proton remains in the nucleus and the electron is ejected as the beta particle, carrying with it some energy.

Beta particles are much smaller than alpha particles and have a charge of  $-1$ , they have a range of up to several meters in air, but can be easily stopped e.g. with 1 cm of Perspex.

### **Gamma Radiation ( $\gamma$ )**

Gamma radiation is a form of electromagnetic radiation emitted from the nucleus and is often emitted with alpha and beta particles. Gamma particles are uncharged, have no mass and travel at the speed of light. Due to these properties they are very penetrating and can travel up to several hundred meters in air. Their penetrating power is such that they require a significant thickness of relatively dense material to stop them (e.g. tens of centimetres of concrete).

### **X-radiation**

This is also a form of electromagnetic radiation, differing from  $\gamma$  only by the mechanism of production. While X-rays are a product of radioactive decay they are generally created artificially when a high speed electron strikes a solid target. The high speed electron passes through or into the shell of an orbiting electron, this interaction with the orbiting electrons results in the release of an X-ray.

## Neutron Radiation

Some radioactive decay results in the release of a neutron from the nucleus of an atom. In some radioactive isotopes this occurs following the adsorption of an alpha particle (Beryllium). Neutrons are also released during fission, which is utilised within nuclear reactors and weapons.

### 1.3.3 Measuring Radioactive Material

Radioactive material is measured using its activity, which is the measurement of the number of atomic nuclei that decay in one second (or the number of nuclear disintegrations per second). Material that undergoes one million decays per second is termed 'more active' than material undergoing one thousand decays per second. The standard unit for measuring activity is the becquerel (Bq), with 1 Bq being 1 disintegration per second.

The decay of any radioactive material can also be predicted, as it is statistical in nature. This principle works from the fact that although it is impossible to predict when an individual atom will disintegrate, due to the very large number of atoms even in the smallest source, the rate of radioactive decay for each radionuclide can be predicted. A common factor used for considering radioactive decay is half-life. This is the time taken for half the radioactive material present to decay and is constant for a specific radionuclide.

The half life is often written as  $T_{1/2}$ , therefore if  $T_{1/2}$  for a radionuclide is 1 day, after 3 days the source material will have an activity of  $1/8$  the initial activity at day 0. There is great variation in the half life of different isotopes, which is demonstrated below:

Uranium-238 = 44,700,000,000 years;

Radium-226 = 1,600 years;

Sulphur- 35 = 87.3 days;

Molybdenum-99= 66 hours;

Oxygen-15 = 122 seconds.

### 1.3.4 Effects of ionising radiation

#### Ionisation

An atom is ionised when sufficient energy is given to an orbiting electron so that the electron is removed from its orbiting field around the nucleus. This energy can come from any of the forms of ionising radiation described above.

The ionisation creates an ion pair, with the ejected electron as the negative ion and the ionised atom as the positive ion. If the negative ion has enough energy it can go on to ionise further atoms therefore causing multiple ionisation. Any atom can be ionised whether it is an atom in a metal bar or an atom within the DNA of the human body.

The ionisation of atoms within biological tissues can result in the tissue temperature being minutely raised. This is caused by the increased amount of vibration in the atomic and molecular structure. This increase in temperature and the resulting chemical changes, can result in harmful biological effects.

The amount of radiation energy that is received by humans can be used to quantify the risk of harm posed to them from the ionisation that occurs. This measurement is the radiation dose,

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with a greater dose representing a higher risk that harm will be caused by the radiation. Two ways of quantifying radiation dose are in use.

- The adsorbed dose is the measurement of the energy that is deposited in a material per unit mass from any interaction with radiation.
- The equivalent dose is the adsorbed dose modified by a radiation weighting factor ( $W_r$ ), to take into account the different biological effects that arise from the irradiation of tissue with different types of radiation.

The equivalent dose takes into account the fact that different types of radiation can be more damaging than others, even if the energy deposited is the same. X-rays,  $\gamma$ -rays and  $\beta$  radiation are all given a weighting factor of 1 as they all cause roughly the same amount of biological damage for a given adsorbed dose. Neutrons and protons have a weighting factor of 5 to 20 and  $\alpha$  particles a factor of 20, which reflects the increased risk of tissue damage .

Adsorbed dose is measure as Grays (Gy) with 1 Gray equal to 1 joule per kilogram. The equivalent dose is the adsorbed dose multiplied by the weighting factor and is given in Sieverts (Sv).

### **Exposure Pathways**

There are two main pathways for the exposure of an individual to a radiation dose, exposure from external radiation, and internal exposure after an individual has ingested or inhaled radioactive material (or via cuts in the skin).

If an individual stands close to a source of radiation they could receive a radiation dose from beta, gamma or X-ray radiation, the magnitude of the dose will depend on the following:

- The activity and nature of the source;
- The distance between the source and the individual;
- The presence and type of shielding between the individual and the source;
- The amount of time that the individual is exposed to the radiation.

In these circumstances the dose an individual could receive from the source can be reduced by restricting access to a safe limit and the addition of shielding around the source.

The intake of radionuclides into the body results in internal organs receiving doses as the radionuclides pass through them. Doses can be received from alpha, beta and gamma radiation.

Radiotoxicity is the harm caused by an intake of a radioactive substance. Radiotoxicity is determined by a number of factors including:

- Type of radioactive emissions – alpha, beta, gamma;
- Radioactive half-life;
- Biological half-life – a measure of the time the radioactive substance will be resident in the body;
- Location of radioactivity – some radionuclides concentrate within specific organs and tissues within the body, and;

- Sensitivity of targeted organs to damage by irradiation.

### 1.3.5 Background radiation

There is a natural level of ionising radiation in the environment, to which everything is exposed to a greater or lesser extent and for the majority of people it is the major source of radiation exposure. This natural radiation comes from a number of sources, for example cosmic rays from outerspace, radioactive elements naturally present in rocks and soils and in the food and drink that we eat. As all organisms have evolved with this radiation exposure it is not considered to be a significant risk to health.

### 1.3.6 Detection and measurement

There are a number of methods that can be employed for the monitoring of dose rates and the detection of radioactive materials, all of which should be undertaken by suitably qualified staff with knowledge of health physics.

Selection of methods of detection and appropriate measuring equipment should also be undertaken by qualified staff as all methods have advantages and disadvantages, with many methods being dependent upon the radionuclides present.

Radiation monitors are available for the measurement of dose rates and the detection of surface contamination. It is important to use the correct radiation monitor for any given set of circumstances.

In some situations the use of a hand held monitor is not appropriate, such as on irregular surfaces. In these situations wipe techniques can be used, these assess the amount of removable contamination. The total activity of the wipe is then assessed and related back to the size of the area that was wiped.

The levels of airborne contamination can be assessed using an air sampler. These pump a known volume of air through a filter which traps particulates. The total activity of the paper is then assessed and related back to the volume of air drawn through the sampler.

## 1.4 Risk Assessment and Radioactive Materials within the Environment

Prior to assessing a land use for the presence of radioactive materials and the risks posed, background information needs to be collected. The background information will include information on the site setting with respect to human and environmental receptors as well as current and historical site activities.

Good practice in dealing with land contamination requires a tiered or staged approach to risk assessment, where each successive stage is based upon more site-specific data. This approach allows each potential risk to be prioritised and ensures that the level of detail involved in the assessment of each risk is proportionate to the risk posed.

In land contamination applications, each stage of risk assessment is underpinned by the concept of establishing the **pollutant linkages**, where **contaminant sources** (substances with the *potential* to cause harm) are linked by **pathways** (means by which a hazard can make contact with or

otherwise affect a receptor) to **receptors** (human beings, water resources, other living organisms and the built environment) which could be affected.

Source-pathway-receptor linkages are assessed to establish:

1. The degree of hazard (extent and types of hazard potentially affecting receptors).
2. The nature and magnitude of the effects arising from the hazard, and the probability (risk) that adverse effects will occur.
3. Whether the risks are acceptable having regard to the current or proposed new landuse and existing guidelines and standards, and taking into account any uncertainties associated with the assessment.
4. Whether action should be taken to control/reduce an assessed risk to acceptable levels.

The hypothetical linkages between identified sources, pathways and receptors are generally presented as a **conceptual model** of the site.

The chemical and physical properties of radioactive material have the same attributes as their non radioactive equivalents. This allows the fate and risk posed by radioactive contamination to be assessed in much the same way as non radioactive chemical contamination.

## 1.5 General Circumstances Where Radioactive Contamination of Soils May Have Occurred

Historical contamination has in many cases occurred due to a lack of understanding of the hazards posed by radioactive materials at the time. Radioactive substances have been used for a wide variety of purposes since the Industrial Revolution, but most have only been subject to regulation since 1963, the year the Radioactive Substances Act (1960) came into force.

Industrial activities have involved the use of materials containing radioactivity in a variety of different contexts:

- Where radioactive materials were employed for their radioactive properties (for example luminising works);
- Where radioactive materials were employed for their non-radioactive properties (for example, gas mantle production); and
- Where radioactive materials were inadvertently handled, or escaped accidentally (for example, lead mining).

Some industries were likely to have been aware of the hazards associated with the radioactivity and applied the controls extant at the time, whereas others were unaware of the issues, and treated the materials in the same way as non-radioactive substances. As a result, radioactive materials arising from both raw material usage and waste disposal have been deposited in the ground at some sites.

This profiles considers both non-natural and enhanced natural sources of radioactive contaminants, with the potential to be found in the environment. It is divided into a number of land uses with the potential to be associated with radioactive contamination of soils. The identification of a land use in this profile does not imply that radioactive contamination will

necessarily exist at such a site. Table 1.1 sets out the typical range of radionuclides that may be associated with each of the land uses described below. Table 1.2 summarises the basic properties of each radionuclide and their daughter isotopes.

Chapter 2	Ministry of Defence land	- land subject to MoD use where activities such as instrument dial refurbishment with luminising paints have occurred
Chapter 3	Munitions Manufacture	- the use of depleted uranium in weapons and armour manufacture
Chapter 4	Mining and extractive industries	- sites where ores (primarily uranium, radium and tin) are mined and handled physically for onward supply to processing facilities
Chapter 5	Metal processing and refining industries	- sites which receive radioactive ores and process them, generating wastes such as tin slags and phosphates
Chapter 6	Waste disposal activities	- landfill sites, incinerators and sewage treatment works
Chapter 7	Luminising works	- sites where luminising paints and powders were manufactured or used by instrument and watch makers
Chapter 8	Gas mantle manufacture	- sites where gas mantles were manufactured using thorium salts in the mantle substrate
Chapter 9	Oil and gas support industry	- sites which have handled descaling of drill pipe operations
Chapter 10	Breakers yards	- sites including scrapyards taking a variety of equipment and metal wastes
Chapter 11	Chemical works/coal-fired power plants	- a range of sites including gas works which may have used uranium catalysts, and coal-fired power stations
Chapter 12	Medical, research, teaching and Manufacturing uses	- experimental laboratories, hospitals and clinics and industrial/university research facilities

**Table 1.1 Summary of the typical radionuclides associated with each class of land use.**

Land-use	Key radionuclides <sup>+</sup>																								
	Uranium-238	Uranium-235	Thorium-232	Radium-226	Lead-210	Polonium-210	Depleted Uranium	Promethium-147	Tritium	Carbon-14	Phosphorous-32	Sulphur-35	Chromium-51	Iodine-125	Iodine-131	Gallium-67	Colbolt-60	Cesium-137	Iridium-192	Indium-111	Thallium-201	Strontium-89	Technetium-99	Krypton-81	
MoD land				✓			✓	✓	✓																
Munitions manufacture							✓																		
Mining and extractive industries	✓	✓	✓																						
Metal processing and refining industries	✓	✓	✓																						
Waste disposal activities	✓	✓	✓						✓	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓		
Luminising works				✓				✓	✓																
Gas mantle manufacture			✓																						
Oil and gas support industry				✓	✓	✓																			
Breakers yards*																									
Coal-fired power plants/Gas works		✓	✓																						
Medical, research, teaching and Manufacturing uses				✓		✓									✓		✓	✓	✓		✓		✓		✓

+ Represents radionuclides at head of decay chain – For daughter isotopes see Table 1.2.

\* Dependant upon source materials

**Table 1.2 Summary information on Radionuclides identified**

Radionuclide	Main Daughter Isotopes	Principal Decay Mode	Half Life	Comments
Uranium-238		Alpha	4.47 x 10 <sup>10</sup> yr.	Naturally occurring radionuclide widely distributed in rocks, soils and sediments
	Thorium-234	Beta	24.1 d	Strongly adsorbed by soils and sediments
	Uranium-234	Alpha	2.45 x 10 <sup>5</sup> yr.	As U-238
	Thorium-230	Alpha	7.7 x 10 <sup>4</sup> yr.	As Th-234
	Radium-226	Alpha	1600 yr.	Most natural Ra-226 decays local to its point of production
	Radon-222	Alpha	3.8 d.	Released from soils and sediments to decay in the atmosphere
	Lead-210	Beta	22.3 yr.	Mainly remains insitu in soils and binds to sediments in aquatic systems. Some in atmosphere from Radon decay
	Bismuth-210	Beta	5.01 d	Some in atmosphere from Radon decay
	Polonium-210	Alpha	138 d	Mainly remains insitu in soils and binds to sediments in aquatic systems. Some in atmosphere from Radon decay.
Uranium-235		Alpha	7.04 x 10 <sup>8</sup>	Naturally occurring radionuclide widely distributed in rocks, soils and sediments
	Proactinium-231	Alpha	3.4 x 10 <sup>4</sup> yr.	Rarely encountered
	Actinium-227	Beta	21.6 yr	Rarely encountered
	Thorium-227	Alpha	18.7 d	Remains insitu in soils and binds to sediments in aquatic systems
	Radium-223	Alpha	11.7 d	Rarely encountered
Thorium-232		Alpha	1.14 x 10 <sup>10</sup> yr.	Very immobile as strongly absorbed to soils and sediments
	Radium-228	Alpha	5.8 yr.	

Radionuclide	Main Daughter Isotopes	Principal Decay Mode	Half Life	Comments
Depleted Uranium	Thorium-228	Alpha	1.9 yr.	Very immobile as strongly absorbed to soils and sediments
	Radium-224	Alpha	3.64 d	Rarely encountered
		Alpha	4.46 x 10 <sup>9</sup> yr.	Not strongly absorbed in soils and maybe mobile, if released to atmosphere will disperse as an aerosol.
Promethium-147	Samarium-147	Beta	2.6 yr.	Will remain bound to soil particles, surface of plants and sediments
Tritium	Helium-3	Beta	12.4 yr.	Low energy beta emitter, thus negligible doses both internally and externally.
Carbon-14	Sodium-14	Beta	5,730 yr.	Low energy beta emitter widely distributed throughout terrestrial and aquatic environments
Phosphorous-32	Sulphur-32	Beta	14.3 d	Move freely through terrestrial environment and has high bioavailability
Sulphur-35	Chlorine-35	Beta	87.3 d	Will accumulate in plants and animals and will distribute equally throughout
Chromium-51	Vandadium-51	X-ray	27.7 d	Emits gamma rays in 10% of transformations. Low bioavailability.
Iodine-125	Tellurium-125	X-ray	59.4 d	Also releases low energy photons. Concentrates in thyroid of animals.
Iodine-131	Xenon-131	Beta (gamma)	8.02 d	Will migrate via surface and groundwater. Concentrates in thyroid of animals.
Gallium-67	Zinc-67	X Ray (low energy gamma)	3.3 d	Low bioavailability External radiation of greatest importance
Indium-111	Cadmium-111	Gamma	2.8 d	Low bioavailability External radiation of greatest importance

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Radionuclide	Main Daughter Isotopes	Principal Decay Mode	Half Life	Comments
Thalium-201	Mercury-201	Gamma	3.04 d	External radiation of greatest importance
Strontium-89	Yttrium-89	Beta	50.5 d	Highly bioavailable
Technetium-99	Rubidium-99	Beta	2.1 x10 <sup>9</sup> yr	Low energy beta emitter of high bioavailability
Krypton-81	Bromium-81	Gamma	2.1x10 <sup>5</sup> yr.	Weak gamma emitter, main exposure is irradiation of lungs
Colbolt-60	Nickle-60	Beta (gamma)	5.27 yr	Decay in-situ as retained in soils and sediments
Cesium-137	Barium-137	Beta (gamma)	30 yr	Binds strongly to clays but available for plant uptake
Iridium-192	Platinum-192	Gamma	73.8 d	Only limited research into environmental fate

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Note: yr = Years

d = Days



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## 2. Ministry of Defence Land

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### 2.1 Background

Ministry of Defence (MOD) encompasses the Army, the Navy and the Royal Air Force. MOD land is land that is, or has been, in the ownership of the MOD, or was used by the MOD in wartime. The various types of sites that the MOD is responsible for include barracks, airfields, naval installations, stores and maintenance and repair facilities. MOD land not considered within this section, are the nuclear licensed sites under MOD ownership, for example some dockyards.

It was estimated at the end of World War 2 that 4.4 million hectares of land throughout the UK had been used for defence purposes. In 1945 a decommissioning exercise was started on large amounts of equipment, a small proportion of which contained radioactive materials. During this decommissioning, radiological waste management standards were significantly different and less exacting than what is considered best practice today (ref 2.1).

In 2000, it was estimated that 240,000 hectares of land remained under MOD ownership. The MOD have advised the Radioactive Waste Management Advisory Committee (RWMAC) that there are "some hundreds" of contaminated sites within its ownership, "some tens" of which are suffering radioactive contamination. It is usually the case that such radioactive contamination is relatively mild and only affects a small fraction of the total site area.

The main difficulty identifying land that may be affected by radiological contamination is the lack of documentary evidence. This is particularly a problem with land, which was divested from MOD ownership shortly after World War 2, or where the land ownership was transferred between sections of the MOD. Due to security reasons there is often little evidence of the existence and use of a site within public records, with sites recorded on maps as their former land use. In many cases, MOD records relating to the former uses and activities of a site were lost or destroyed after the war (ref 2.2).

Where there is a lack of documentary evidence, the identification of areas which may be affected by radioactive contamination must be based on local knowledge and past experience of site activities.

Small quantities of radioactive materials are still used on some MOD sites, these include betalights, electronic valves and sealed radioactive sources for instrument calibration, with the use and disposal of these materials being strictly controlled within the MOD. The use of such sources are recorded by the MOD, with records kept by Dstl Radiological Protection Services (DRPS).

## 2.2 Activities

### 2.2.1 Luminising Workshops

Some MOD sites within the UK contained luminising workshops, where instruments were painted with radium luminising paint. Radium luminising paints were used between the 1930's until the late 1950's, the time of greatest use being during the Second World War. Luminising paint was used on equipment such as dials to be used in military vehicles, aircraft and ships and has also been seen to be used to mark kerbstones in military bases (ref 2.2). Although promethium-147 and tritium have been used in later luminising works they have not, to date, been found to have caused significant ground contamination (ref 2.1).

Former luminising workshops may be contaminated with residual levels of radium. Workbenches, walls and floors, sinks where articles were cleaned, associated pipe work and drainage systems, light switches, door handles, window sills, radiators, broom cupboards, storerooms and cloakrooms have been found to be contaminated. Many such facilities have already been remediated by MOD and others, but some are likely to remain unchanged.

Areas external to the buildings may also have been impacted, and these can include areas within throwing distance of windows and burial sites in the soft ground surrounding buildings.

### 2.2.2 Maintenance Areas and Workshops

Most MOD sites contained maintenance and workshop areas, although not all of these dealt with luminised instruments. The majority of the workshops that maintained and repaired military equipment were run by a branch of the army called the Royal Electrical and Mechanical Engineers (REME) (ref 2.3).

Activities carried out in REME workshops included the replacement and repair of luminised instruments from military vehicles. This resulted in the generation of small amounts of waste products containing radium, which were disposed as described in Section 3.3.

### 2.2.3 Dismantling and Burning Grounds

After World War 2 a lot of military equipment was taken out of service. This involved the dismantling of the equipment, generally for scrap value before burying the remaining wastes. These wastes were often burnt prior to burial, to reduce the volume.

The burning of waste material on burning grounds was an established disposal technique on MOD bases and not limited to radioactive materials. Former burning areas can still be identified on some sites. They are generally circular areas, set away from other buildings. The ground in these areas is often stony, ashy ground lacking in vegetation. On some bases the burning areas have been remediated or resurfaced to allow other uses.

### 2.2.4 Firing Ranges

Depleted Uranium (DU) rounds have been tested on a limited number of military testing ranges in the UK (ref 2.1). DU has been used by the MOD since the early 1990's as a component in rounds for piercing heavy armour. The MOD has commissioned monitoring work on ranges where Du has been used and found that this has had a negligible impact on the environment

other than in some localised areas (ref 2.4).

One of the properties of DU is that it is pyrophoric causing it to explode/ignite on impact. This property causes the production of an uranium containing aerosol when the DU round hits a target, which will result in the surface deposition of DU around the bunkers.

#### **Case Study – Former MOD Compass Observatory (ref 2.1)**

The site covers approximately 87 hectares of land in southern England. Approximately half of this land was radioactively contaminated to some degree, with the site consisting of protected parkland, buildings (including listed buildings), areas and landfill and domestic gardens. The site was in MOD use from 1919 to 1992 as a manufacturing facility for direction – finding equipment and was the MOD’s sole source of radium paint. Radium-226 was not used at the site after 1969.

Although it was believed that Promethium-147, polonium, tritium and a number of other radionuclides were used on the site in the early 1970’s, radium-226 was the only source of radioactive contamination found at the commencement of remedial works. The contamination took the form of ash and clinker from the on site use and disposal and accidental spillage of radium paint. Contamination was found in and below site workshops, in footpaths and informal disposal areas around the site, within the site drainage system and on rocks and kerbstones painted with radium paint to aid in vehicle movements during World War 2 blackouts.

## **2.3 Waste Handling**

Historical radioactive contamination has commonly arisen from the lack of understanding of the effects of radioactivity and lack of control of radioactive wastes. This is either from within luminising workshops, which were present on some bases, or from the maintenance or dismantling of vehicles, aircraft and ships. There are two waste forms containing radium contamination:

- Primary - Artefacts contaminated with luminising paints;
- Secondary - Combustion residues containing radioactive contamination;

Primary waste products from the luminising workshops included empty paint vials, brushes and broken dials. These would have either been buried in a waste disposal area on the site, or would have been incinerated. The ad hoc burial at localised disposal points around the site was generally confined to soft areas around workshops and maintenance areas. Incinerating the waste materials did not remove the radioactive element of the waste, but concentrated it into a reduced volume of material (ref 2.2). The resulting ash from incineration was either used as a granular fill within the site or buried in waste disposal areas. There have also been cases where instruments have been found in burial areas.

In many cases, records of the location of waste disposal areas were not kept, making identification difficult. One of the main sources of information to allow identification will be local knowledge. Geophysical survey techniques are also useful in identifying buried structures such as old foundations, as well as areas of waste disposal and disturbance. The condition of vegetation can also indicate the areas of waste disposal.

Waste disposal areas may contain waste to a significant depth, which may inhibit the ability to detect radioactive contamination due to attenuation by overlying materials.

Combustion residues from the incinerators and burning areas were often used on MOD sites as an aggregate used in landscaping and highway construction. Common areas to find such material are therefore:

- Under roads and footpaths
- Within landscaped banks and mounds
- Areas where former buildings have been demolished and the land levelled
- Areas around the incinerators and boiler houses, where combustion residues were spread.

Ground contamination from current practices could be present on DU firing ranges. The DU rounds are fired into target bunkers filled with sand contaminating the sand with uranium. When the bunkers are full they would be cleared by excavating the sand and fired projectiles, this waste material is likely to have been buried within the firing range area.

A variety of other waste could be found on MoD land, dependent upon the historical or current activities. The industry profile series covers many of these activities and will detail associated waste products and some waste handling practices.

## 2.4 Potential Contaminants

The primary historical radiological contaminant found on MOD site is Radium-226. The likely physical form of Radium-226 is solid, either as artefacts or as combustion residues in a soil matrix.

Radium-226 is a radioactive isotope with a half life of 1600 years. It is a naturally occurring radioactive isotope and is a daughter product from the decay of uranium. Radium is an alpha emitter releasing some low energy gamma radiation. As radium is an alpha emitter there is only a low risk of a significant dose being received by direct irradiation. The ingestion or inhalation of radium has the potential for a high internal dose to be received by sensitive organs within the body.

Radium contamination on MOD sites will be contained within a non mobile form with there being little or no leaching and movement from radium dissolved in groundwater. Some movement of contamination can occur in soils with a high ash content, with the finer ash particles being moved by the groundwater. This can result in the collection of Radium-226 contaminated ash around field drains.

More recently Promethium-147 and tritium were used in luminising operations. Promethium-147 is a beta emitter, also releasing gamma radiation. Its half life is a lot lower than that of radium at 2.6 years. Tritium is an isotope of hydrogen, it is a pure beta emitter with a half life of 12.3 years. The fact that these compounds have only had a limited use, with a much lower half life compared to that of radium, means that they are less likely to have caused a significant amount of soil contamination on MOD sites.

DU is a recent source of contamination and has only been in use since the early 1990's in armour piercing munitions. Uranium isotopes emit a range of radiations but are primarily alpha emitters, therefore the greatest concern is from internal doses to sensitive organs received after ingestion or inhalation. Uranium is also chemically toxic to humans (ref 2.5 and 2.6).

## **2.5 Significance in the Environment**

Radiological contamination of MoD land presents a relatively low level of risk to health and the wider environment, and has only occurred on a small proportion of MOD land. Radiological contamination on such sites is also generally limited to small proportion of their areas. Many sites have been subject to remediation and no longer present any concerns, and a programme of assessment of land is in hand to deal with remaining sites. Contaminants on such sites are alpha and low energy beta and gamma emitters, with the main risks from internal doses received via ingestion and inhalation.

## **2.6 Relevant Information Sources**

- 2.1 Radioactive Waste Management Advisory Committee, Advise to Ministers on the MoD Arrangements for dealing with Radioactively Contaminated land, 2002.
- 2.2 K.J.Gibbs, Radium Contamination, An Overview of UK Ministry of Defence Experience, DRPS 1993.
- 2.3 Land Contamination: Technical Guidance on Special Sites: MOD Land, Research and Development Technical Report P5-042/TR/O1, Environment Agency 2001.
- 2.4 Proposal for a Research Programme on Depleted Uranium, MOD, 2002  
[http://www.mod.uk/issues/depleted\\_uranium/du\\_research.htm](http://www.mod.uk/issues/depleted_uranium/du_research.htm)
- 2.5 The Royal Society Report on Depleted Uranium Part 1, The Royal Society 2002
- 2.6 The Royal Society Report on Depleted Uranium Part 2, The Royal Society 2002



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## 3. Munitions Manufacture

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### 3.1 Background

The manufacture of munitions has occurred at sites across the UK, under the auspices of both public and private sector organisations. However, certain munitions utilise the physical properties of depleted uranium (DU), and this document addresses the radiological contamination issues associated with the use of DU.

Munitions manufacture utilising DU has been undertaken on a very small number of sites in the UK, with most operating during a time when waste disposal practices were regulated under Radioactive Substances Act 1960 and 1993.

Uranium occurs naturally as three isotopes: Uranium-234, Uranium-235 and Uranium-238. The most abundant form is Uranium-238 which accounts for over 99% of all natural uranium, followed by Uranium-235 at 0.7%. The nuclear industry requires enriched uranium, in which the concentration of Uranium-235 is enhanced to approximately 3%. DU is produced as a by-product of this enhancement process, and contains predominantly Uranium-238, with only 0.2% Uranium-235. DU is therefore less radioactive than naturally occurring uranium, but it exhibits no difference in chemical behaviour or toxicity (ref 3.1).

DU has a high density ( $19\text{g/cm}^3$ , which is 1.7 times the density of lead), and is a very hard metal, which makes it suitable for use in armour piercing munitions, as well as other uses such as radiation shielding, rotors, flywheels and counterbalances in aircraft. In addition it is pyrophoric (catches fire and sparks when it impacts or is impacted). DU is often used in ammunition as an alloy with 0.75% titanium to further increase its hardness (refs 3.1,3.2,3.3).

Experimental firing of DU weapons began in the 1960s in the UK, and a programme to develop armour penetrators followed in the early 1980s. There is little historical information about the manufacture of early DU munitions, however publicly available information on current DU munitions is available.

DU munitions have historically been made in Britain by Royal Ordnance. Following their acquisition by British Aerospace and merger with The Land and Naval Systems section of Marconi Electronic systems, Royal Ordnance was renamed RO Defence (ref 3.4). It is known that DU munitions were made until 2002 at the RO Speciality Metals Facility at Featherstone, however operations with DU ceased here due to completion of their contract.

### 3.2 Activities

Two types of DU ammunition are currently used in the UK (ref 3.5):

- 120mm anti-tank rounds fired by tanks
- 20mm rounds for a weapons system used on some Royal Naval ships.

The munitions manufacture sites which make, or have made weapons utilising DU will have stored and processed significant quantities of DU. For example the large calibre anti-tank rounds contain approximately 4-5kg of DU each (ref 3.1). The DU is imported to the munitions manufacture site, possibly from the overseas sources such as the United States. It will require processing to form it into the required penetrators.

### 3.3 Waste Handling

The use of DU does not pre-date the first Radioactive Substances Act of 1960, and therefore wastes should have been disposed of in accordance with these regulations. There is the possibility though, that some swarf from very early operations (prior to the enforcement in 1963 of RSA 1960) may have been disposed of by burning, and the uranium oxide ash buried locally (ref 3.6).

### 3.4 Potential Contaminants

Depleted uranium has been reported to contain traces of radioactive substances other than just uranium. These trace substances include americium, neptunium, plutonium, technetium, and Uranium-236, all of which could occur if the DU was sourced from reprocessed irradiated uranium from reactors. It is reported that these trace substances account for less than 1% of the total radiation dose from DU.

The radiation from DU is predominantly alpha particles, but some beta and gamma radiation is also present. All of the uranium-isotopes present within DU have relatively long half lives (ref 3.1):

- Uranium-238 –  $4.4 \times 10^9$  years
- Uranium-235 –  $7 \times 10^8$  years
- Uranium –234 –  $2.4 \times 10^5$  years

Uranium also exhibits chemical toxicity, and is particularly associated in humans with detrimental effects to the kidneys.

The environmental fate of DU depends upon the form of its release into the environment (eg dusts usually of uranium oxides or fragments of metallic DU), and on environmental factors such as pH, water content of soil etc. The alloying of DU with titanium, as commonly used in munitions to reduce the rate of corrosion. Experiments where a whole penetrator (1cm in diameter, and 15cm long) was allowed to corrode in the environment under corrosion favourable conditions showed that approximately 90g of DU was released into the environment per year, indicating that whole penetrators would remain as metallic DU for 5-10 years (ref 3.7).

There is an existing Industry Profile (Engineering works: mechanical engineering and ordnance works) which deals with conventional chemical contaminants which may be associated with munitions manufacture (ref 3.8).

### 3.5 Significance in the Environment

Radiological contamination at munitions manufacture sites presents a relatively low level of risk to health and the wider environment. The principal decay mode of DU is via alpha decay, and therefore the greatest risk to human health would result from an internal dose arising from the ingestion, inhalation or injection of materials containing DU.

### 3.6 Relevant Information sources

- 3.1 The Royal Society (2001) – The health hazards of depleted uranium munitions. Part I.
- 3.2 Military Use of Depleted Uranium [www.eoslifework.co.uk/pdfs/DU2102A3a.pdf](http://www.eoslifework.co.uk/pdfs/DU2102A3a.pdf).
- 3.3 Rokke, D (date unknown) Depleted Uranium: Uses and Hazards
- 3.4 Select Committee on Defence, Submissions from BaE systems on Royal Ordnance Defence Strategy, 24 January 2002. <http://www.parliament.the-stationery-office.co.uk/pa/cm200102/cmselect/cmdfence/779/779ap22.htm>
- 3.5 Parliamentary Office of Science and Technology (2001) – Depleted Uranium. Postnote Number 154.
- 3.6 Department for Environment, Food and Rural Affairs (2001) Historic Practices in the UK which have utilised Radioactive Materials. Report ref DETR/RAS/00.005. [www.defra.gov.uk/environment/radioactivity/research/complete/historic/](http://www.defra.gov.uk/environment/radioactivity/research/complete/historic/)
- 3.7 The Royal Society (2001) – The health hazards of depleted uranium munitions. Part II.
- 3.8 Department of the Environment (1995) – Industry Profile. Engineering works: mechanical engineering and ordnance works.



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## 4. Mining and Extractive Industries

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### 4.1 Background

The following mining and extractive industries, with the potential for handling radioactive materials and producing radioactive wastes are discussed in this section:

- Uranium mining
- Ferrous and non-ferrous metal mining
- Coal mining

These industries can be split into two categories, those which mined radioactivity (such as uranium mines) and those which produced radioactive bi-products (such as tin mines).

Mining activities carried out in rocks that have deposits of naturally occurring radioactive materials (NORM), with varying amounts of uranium, thorium and daughter isotopes. There were a number of other processes and activities that produced waste and products with elevated levels of NORM, that have not been considered in this document. They include the extraction of geothermal water and the excavation of rare earth metals and gems. These processes have not been carried out to any significant extent in the UK.

The Department of the Environment derelict land survey of 1993 identified 9191 hectares of land that contained spoil heaps, of which 4109 hectares were from collieries, 3003 hectares are from metalliferous mines and 2079 from other mines (ref 4.1).

Many mining operations are also linked to ore processing and manufacturing industries. The operation of such industries, including potential radiological significance to land contamination, are discussed in Chapter 5.

#### 4.1.1 Uranium mining

Uranium mining was focussed on production of uranium to be utilised for its radioactive properties, although early mining activities were concerned with non-radioactive properties. Uranium from early UK mines was for use in the glazing of pottery, with the majority sent to the Potteries in Staffordshire. UK mines also mined uranium ore for the production of radium (a daughter isotope), which was generally used for its radiological properties.

The mining of uranium in the UK was carried out by excavation in open pits or underground mines. The choice between open pit and underground methods was made by the amount of barren rock that needed to be removed to allow the extraction of the ore.

Uranium was historically mined in a few locations in the south west of England. In some of these locations the uranium ore was processed on the same site.

### **4.1.2 Metalliferous mining**

In metal and coal mining activities materials are mined for their non-radiological properties. Historically, these activities have not been considered as industries with potential radiological impacts on man and the environment, and have not been under radiological control.

Copper ore is extracted from rock of two basic types, white and black rock. The black rock is more bituminous and contains higher concentrations of uranium. Copper was one of the first commercial mining activities in the UK and was based alongside tin mines in the south west. The mining of tin and copper in the south west grew from around the 12<sup>th</sup> century, until the 18<sup>th</sup> century when many of the uses of copper and tin were replaced with iron (Ref 4.2).

Iron ore has been mined throughout the UK for many centuries. In many cases the ores used were found accompanied by coal deposits. Principal mining areas in the North East, Yorkshire and the Midlands. The mining for iron ore began with the use of bottle necked pits, but these though only produced small quantities before the pits flooded. The improvement in mining techniques and the use of drainage techniques (taken from the tin and copper mining industries) in the 1700's, greatly increased the production of both iron and coal (ref 4.3). Due to economic reasons and an increase in metal recycling there are no longer any active lead, copper or tin mines in the UK.

The most common lead ore found in the UK was Galena (lead sulphate) which occurred in association with minerals such as quartz, calcite and barytes. Lead has been mined in the UK since Roman times, increasing between the 13<sup>th</sup> and 16<sup>th</sup> centuries due to its demand for use in monasteries and large houses. It became important again in the beginning of the 19<sup>th</sup> century and the industrial revolution. Lead mines were distributed throughout the UK, with mines found in Scotland (Dumfries and Galloway), Durham, Yorkshire, Derbyshire, Shropshire, Wales and Cornwall (ref 4.4).

The mining of zinc was also historically carried out in the UK. Zinc was very rarely mined alone, and often accompanied the mining of lead ores. Historical records show that the greatest number of zinc producing mines in the UK were active around the 1900's. The majority (23) were located in Wales, with a further 17 located in England and Scotland. By 1945 there were just two active mines in the UK - in Cornwall and Cumberland, and both mines also mined Lead (ref 4.5). Lead and Zinc mining has now completely ceased in the UK.

### **4.1.3 Coal Mining**

Large scale coal mining began in the 1800's in the UK beginning with open pit mines followed by deeper collieries after the improvement in mining techniques. Coal mines were found in many regions of the UK including the North East, the Midlands the South West and Wales (ref 4.6).

## **4.2 Activities**

Activities resulting in the contamination of land by radionuclides are primarily associated with the waste products, and are covered in section 4.3 below.

## 4.3 Waste Handling

Waste rock is the main waste product from the mining of ores, and this is often stored on the site in a spoil heap and can be accompanied by other wastes. On sites where ore processing has also undertaken, the spoil heap can also include waste sludges and slag.

The sizes of the spoil heaps are largely dependent on the size and form of the mining operations. In some cases, spoil has been used to infill valley features adjacent to the deeper mines.

Some of these abandoned sites have been greatly disturbed with spoil being removed and used elsewhere. Undisturbed sites have become inhabited by, in some cases rare metal tolerant plant species.

Radioactivity concentrations in the feed materials for different metal industries are generally low. Wastes from the tin industry produce slightly higher concentrations of NORM. It is the production of slag waste from smelting operations which contains elevated levels of radionuclides, and this is discussed further in Chapter 5.

## 4.4 Potential Contaminants

### 4.4.1 Uranium mining

Uranium mining could have resulted in the contamination of an area by elevated concentrations of NORM. Studies of the uranium mining industry in the former East Germany have shown that wastes of barren rock contained on average between 15 to 25 mg/kg of uranium with a total activity of 2 to 5 Bq/g. Cut-off grade rock had an average uranium concentration of 150 mg/kg with a total activity of approximately 30 Bq/g (ref 4.6).

The main contaminant exposure pathway to human receptors is from the inhalation of dust containing NORM radionuclides, the most important radioisotope in this pathway is Radium-226 due to its high radiotoxicity. Older spoil heaps tend not to generate great amounts of dust as they have a vegetation barrier, and this exposure pathway is likely to be limited to times where disturbance of the spoil would increase the generation of dust (ref 4.7).

The main environmental pathway is from the leaching and transport of Radium-226 from spoil heaps. The groundwater transport will however be retarded by soils and any radium reaching groundwater and surface water bodies is likely to be diluted to undetectable levels. Silt in rivers and streams near to uranium mines often have elevated radioactive isotope concentrations, and there have also been cases near to uranium mines, where there has been a build up of radium within fauna and flora.

### 4.4.2 Metalliferous mining

Metalliferous mining wastes can also contain potentially harmful concentrations of NORM contaminants. These will generally be at lower concentrations in comparison to uranium mill tailings. The same human and environmental exposure pathways will exist on spoil heaps as described for uranium mining spoil.

Soils and spoils of metalliferous mining sites and the surrounding area may contain considerably elevated concentrations of toxic metals. The extent of such contamination within and between sites may also vary considerably. In sites where ore processing and smelting has

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taken place alongside mining, spoils can contain deposits with up to 50% total metals whereas site where just barren rock has been discarded may have metal level of little above background (ref 4.2).

#### 4.4.3 Coal mining

There is little information regarding the radionuclide content and activity of colliery wastes. The average specific activity in coal itself is generally around 0.02 Bq/g for both uranium and thorium (ref 4.2).

### 4.5 Significance in the Environment

The majority of the radionuclides present in the mine wastes are alpha emitters with some low energy beta emitters, the major risk on such site is therefore from internal doses received from the ingestion or inhalation of contaminated materials.

Although uranium mine wastes will contain higher activity concentrations of NORM, the number of sites containing such wastes in the UK was limited to a few small scale operations in south west England.

Metalliferous mine wastes will have a lower activity concentration than that of uranium mine wastes. They are likely to have a higher significance in the environment due to the prevalence of mining sites around the UK.

### 4.6 Relevant Information Sources

- 4.1. David Wickers et al, Survey of derelict land in England – 1993 HMSO.
- 4.2. General State of Industry – Tin Mines. <http://www.history.rochester.edu/steam/lord/2-3.htm>
- 4.3. General State of Industry – Coal Mines and Iron Works. <http://www.history.rochester.edu/steam/lord/2-2.htm>
- 4.4. A Brief History of Lead Mining in the Yorkshire Dales <http://www.more.freeserve.co.uk/leadmining%20history.htm>
- 4.5. Lists of UK Mines <http://freepages.genealogy.rootsweb.com/~cmhrc/lomindex.htm>
- 4.6. Hildegard, Vandenhove et al Investigation of a possible basis for a common approach with regard to the restoration of areas affected by lasting radiation exposure and a result of post or old practise or work activity CARE, 1991.
- 4.7. Simon Webster et al. The legacy of Uranium Mining in Central and Eastern Europe – A view from the European Union. European Commission, Directorate-General Environment. 1998

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## 5. Metal Processing and Refining Industries

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### 5.1 Background

Metal processing and refining industries involve the processing of metal ores to produce metals and the subsequent purification of these metals. The activities that are included in this process are:

- Smelting (primary smelting), the production of metal from ore,
- Refining - methods to improve the purity of the metal obtained from smelting,
- Foundry melting out, production of primary metal products such as ingots and metal rolls.

The main radiological concern in these industries is the presence of naturally occurring radionuclides within the base ores. The nuclides are mostly removed during the processing and purification of the ores, and form part of the waste produced during each process.

The following major metal industries have operated in the UK (refs 5.1, 5.2, 5.3):

- Aluminium
- Copper
- Iron and steel
- Lead
- Tin
- Zinc
- Magnesium
- Nickel

In addition this chapter will look at the manufacture of phosphate fertilisers which produce waste where radionuclides have been concentrated by the refining process.

Metal processing activities have been carried out in the UK since the Iron Ages. These early industries were situated near to metal ore mines, such as tin in Cornwall and lead and copper in Derbyshire and Wales.

The industrial revolution saw a rapid increase in the use of metals and metal production in the UK, to such an extent that metal ores were imported into the UK from overseas. The location of the industries also changed with smelting and refining work situated near to coalfields (for power source) and near to ports (taking advantage of cheaper imported ores).

There was a decline in the metal smelting industry in the UK during the 20<sup>th</sup> century, due to ore producing countries undertaking primary smelting. The industry now focuses the majority of refining on a smaller number of large sites (ref 5.4).

Many metal manufacturing and refining industries are also linked to mining operations. The operation of such industries, including potential radiological significance to land contamination, are discussed in Chapter 4.

## 5.2 Activities

The operations undertaken to produce metals from their ores varies depending on the metal. A brief description of each is given below, together with an indication of the typical nuclides associated with the base ores.

### 5.2.1 Aluminium

Aluminium is the most abundant metal in the earths crust, the most important aluminium bearing mineral being Bauxite  $[(AlFe)_2O_3]$ , which can contain up to 55% aluminium as well as concentrations of thorium. Bauxite is first refined to produce alumina by the Bayer process which involves digestion with caustic soda with resulting hydrate crystallised in a kiln. The alumina is then reduced to produce metallic aluminium by electrolysis.

### 5.2.2 Copper

The production of copper begins with the separation of the ore from the dead rock. Two rock types produce the ore, white and black rock, the black being more bitumous and containing more uranium. The ore can then be roasted to produce a crude copper with slag and raw gas as waste materials. Alternatively, the ore can be crushed, washed, melted and reduced, the oxides and carbonates are then leached with sulphuric acid, the copper is then removed from solution by electrolysis. The waste rock contains varying concentrations of uranium and daughter isotopes.

### 5.2.3 Iron and Steel

The ore is pre-processed in sintering and pelleting plants in preparation for the blast furnace, and this can result in the production of dusts containing volatile radionuclides Lead-210 and Polonium-210. During this process coal is converted into coke with the tars also containing Lead-210 and Polonium-210. Within a blast furnace the iron is reduced and the coke oxidised, producing pig iron, slag and blast furnace ash. Other radionuclides associated with slags and sludges include Uranium-238 and Thorium-232.

### 5.2.4 Lead

The main commercial source of lead came from Galena ore (Lead Sulphide). The lead was extracted from the ore by dry crushing, wet grinding to produce a slurry, gravity classification and flotation. The lead minerals were then smelted and refined by the removal of copper, arsenic, antimony etc. Radium-226 and Thorium-232 were associated with lead furnace slag with lower concentrations of uranium and other daughter isotopes also present.

### 5.2.5 Tin

Tin rich residues and ores were smelted to produce a molten metal stream. This was then separated into tin, lead, bismuth and lead/bismuth alloy. Uranium-238 and Thorium-232 was associated with tin ores. Slags are likely to contain both the above and daughter products such as Radium-226, Lead-210 and Polonium-210.

### 5.2.6 Zinc

The main ore used for zinc production was a sulphide form called sphalerite, which also contained iron and cadmium as impurities. The ore was crushed, ground and upgraded by flotation, the product was then smelted and refined by distillation or electrolysis. Uranium-238, Radium-226, Lead-210 and Thorium-230 are associated with zinc smelting.

### 5.2.7 Nickel

Nickel was produced by heating a nickel rich concentrate in a stream of hydrogen and carbon monoxide to form nickel carbonyl particles, which decomposed into elemental nickel and carbon monoxide.

### 5.2.8 Phosphate

Phosphate fertilisers were produced from processing phosphate rich rocks (tricalcium phosphate), and these rocks also contained small proportions of uranium and its decay products. The phosphate rock was digested in sulphuric acid to produce phosphoric acid and a waste sludge (phosphogypsum). The phosphoric acid was then used to digest more rock and produce a 'triple super' phosphate (ref 5.5, 5.6).

Phosphogypsum contains approximately 80% Radium-226, 30% Thorium-232 and 14% Uranium-238 of the concentrations found in the mined ore. One tonne of phosphate results in the production approximately four to five tonnes of phosphogypsum.

The above method of production ceased in the UK in the 1980's as it became more economically viable to import the intermediate ammonium phosphate and phosphoric acid.

## 5.3 Waste Handling

Wastes that arise from the refining of metal ores consist of slag from the blast furnace; dust/slurry collected in filters and from the lead and zinc industries and dross (scum formed on the surface of molten metal by oxidation). Some of these materials, mainly the dusts, could be recycled, and were often mixed with raw materials.

The production of copper produced three different waste residues, these were waste rock, dust/sludge and slag. The smoke that was also produced in copper production contains fine dust particles with elevated concentrations of Lead-210 and Polonium-210, although these were partially removed by air filters. They could be further purified by passing them through an intensive purification scrubber unit, which produced a waste sludge, also with elevated concentrations of Lead-210 and Polonium-210 (ref 5.4).

Environmental legislation has led to a general improvement of waste management practices throughout the industry. The waste materials produced are chemically contaminated and require

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disposal to a licensed site. Many sites adopt a temporary storage policy so that waste materials can be disposed of in a more cost efficient way, and the wastes are generally stored in banded areas.

Areas with an extensive history of metal processing and manufacture will not necessarily have adopted such waste management practices and the disposal of waste materials could have occurred either within the site or at an appropriate location nearby. In some cases slags and other waste products were used in landscaping either on site or off site.

This disposal practice may have led to the accumulation of materials containing elevated levels of NORM, that could present a hazard to human health or the environment.

## 5.4 Potential Contaminants

The potential radioactive contaminants from the production of metals and phosphate fertilisers are the naturally occurring radionuclides of the uranium decay chain (see Table 1.2).

The Bauxite ores used in the production of aluminium contain between 0.04 and 0.5 Bq/g of Thorium-232 and similar levels of Uranium-238 (ref 5.4), the concentrations are slightly increased in the Red Sludge waste that is produced after electrolysis.

The concentrations of naturally occurring radioactive materials found in iron ore are low. Problems do however occur during the production of steel with the concentration of the contaminants within the blast furnace. Amounts of contaminated dusts produced are about 2000 tonnes for every million of steel, with an activity of around 30 to 100 Bq/g of Lead-210.

The production of lead only gives rise to radioactively contaminated material in the blast furnace. Slag from the blast furnace contains substantial amounts of NORM with activities of around 0.26 Bq/g Radium-226.

Typical concentrations of NORM contained in Tin ore are 1 Bq/g for Uranium-238 and 0.3 Bq/g Thorium-232. The slag produced in the blast furnace contains approximately 4 Bq/g of Thorium-232 and Radium-228 and 1 Bq/g of Uranium-238 and Radium-226.

Phosphate ores contain approximately 1.5 to 1.7 Bq/g of Uranium-238 and similar activities of Radium-226. Lower concentrations of NORM are found within phosphogypsum, blast furnace slag and dusts (see table 5.1).

Table 5.1 summarises the activity concentration of radionuclides found in common waste products from metal processing and refining industries in the European Union.

### Case Study – Tin Slag

A former industrial site in North West England was proposed for residential development in the late 1990s. During the course of a standard contamination assessment process, the land was shown to have had various industrial uses including a timber yard and treatment works and a chemical works which manufactured tanning extracts and paints. A rail track running from a tin works in the area was also identified.

Intrusive site investigations identified elevated concentrations of various heavy metals (including tin) and inorganic contaminants such as sulphur, sulphate and asbestos. The Made Ground encountered comprised ash and clinker with brick, rubble and timber. In addition, the presence of tin slag was noted in some exploratory holes. Tin slag exhibits enhanced concentrations of the uranium-238 and thorium-232 decay chains which occur naturally in the tin ore. The smelting process concentrates these radionuclides in the furnace slag which is produced as a waste product.

The tin slag was found to be present as a black, vitreous material with a high density, which had been used as hardcore beneath areas of concrete or asphalt and was later shown have been used in the foundations of about 25% of the buildings on site.

Two samples of the tin slag encountered during the intrusive investigations were analysed and found to contain the following activity concentrations of radionuclides:

Uranium-238 decay chain	Radium-226	1.0Bq/g
	Lead-214	0.73 Bq/g
	Bismuth-214	0.7 Bq/g
Thorium-232 decay chain	Actinium-228	1.0 Bq/g
	Lead-212	0.95 Bq/g
	Bismuth-212	1.1 Bq/g

The activity concentrations of the uranium-238 decay chain were approximately ten times higher than uncontaminated soil, and those for the thorium-232 decay chain were approximately thirty times higher than normal soil.

## 5.5 Significance in the Environment

The UK has a long history of metal processing with a large number of historical sites located around the country. The greatest risk is from sites that were operational prior to the regulation of waste disposal. The majority of the radionuclides that are present in the wastes are alpha emitters with some low energy beta emitters, the major risk on such sites is therefore from internal doses received from the ingestion or inhalation of contaminated materials. The levels of contaminants could have been concentrated to significant levels in the waste materials.

## 5.6 Relevant Information Sources

- 5.1. Metal manufacturing, refining and finishing works (lead works), DoE, 1995.
- 5.2. Metal manufacturing, refining and finishing works: non ferrous metal works (excluding lead works), DoE, 1995.
- 5.3. Metal manufacturing, refining and finishing works (iron and steel works), DoE, 1995.
- 5.4. Vandenhove et al, Investigation of a possible basis for a common approach with regard to the restoration of areas affected by lasting radiation exposure as a result of past or old practice or work activity, CARE, 1999.
- 5.5. Historic and current UK use of radioactive materials, R & D Technical report No P307, Environment Agency 1999.
- 5.6. Chemical works, fertiliser manufacturing works, DoE, 1995.

**Table 5.1 Typical activity concentrations for waste products of the metal processing industry (ref 5.7)**

Material	Activity Concentration (Bq/g)	Radionuclides
Aluminium		
Bauxite	0.037-0.530	U-238
Red Sludge	0.041-0.527	Th-232
Copper		
Slags (old 200-500 yrs)	0.800-1.370	Ra-226
	0.500	K-40
	0.660-1.550	Pb-Po-210
	0.050	Th-232
Slags (Since 1880)	0.270-1.040	Ra-226
	0.400	K-40
	0.120-0.680	Pb-Po-210
	0.050	
Dead Rock (white)	0.010-0.140	Ra-226
	0.040-0.110	Pb-210
Dead Rock (black)	0.250-0.810	Ra-226
	0.220-0.760	Pb-210
Sludge	0.140-0.740	Ra-226
	0.2	K-40
	3.620-21.540	Pb-Po-210

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Material	Activity Concentration (Bq/g)	Radionuclides
	0.020	Th-232
Roast Product	0.170-0.440	Ra-226
	2.330-18.190	Pb-Po-210
Iron and Steel		
Slags	0.150	U-235 Pb-210
	0.150	Th-232
Sludge	30-100	Pb-210
Coal Tar	0.110	Pb-210
	0.140	Po-210
Dust scales	<200	Pb-Po-210
Fumes	0.010	Po-210
Lead		
Furnace slag	0.036	Th-232
	0.265	Ra-226
Tin		
Ore	1	U-238
	80	Th-232
Slag	1	U-238
	4	Th-232
	1	Ra-226
	10	Pb-Po-210
Fumes	200	Po-210
Zinc		
Mining waste	<0.019	U-238
	0.007	Ra-226
	<0.015	Pb-210
Electrolysis waste	<0.006	U-238
	0.008	Th232
	0.008	Ra-226
	0.096	Pb-210
Slag	0.033	U-238
	0.030	Ra-226
	0.044	Pb-210

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Material	Activity Concentration (Bq/g)	Radionuclides
Phosphate		
Phosphogypsum	0.5	U-238
	0.01	Th-232
	0.7	Ra-226
	1.3	Pb-210
	0.9	Po-210
Furnace Slag	1	U-238
	1	Ra-226
Dusts	1	Pb-210

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## 6. Landfills, Sewage Works and Incinerators

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### 6.1 Background

This chapter deals with how industries producing radioactive wastes may affect our waste disposal facilities such as landfills, sewage works and incinerators. There are two existing Industry Profiles which are relevant to this section:

- Waste recycling, treatment and disposal sites: Landfill and other waste treatment or waste disposal sites (includes information on incinerators)
- Sewage Works and Sewage Farms.

#### 6.1.1 Landfills

The existing Industry Profile relating to landfills (ref 6.1), states that there is the potential for a large range of contaminants to be present at landfill sites, but does not present a definitive list of potential contaminants. Some waste materials may also exhibit radioactive properties, either because the landfill is licensed to receive such material (subject to the waste being below relevant activity levels set out in the landfill licence), or because they have been deposited unknowingly, illegally or prior to the implementation of Control of Pollution Act 1974 (CoPA 1974).

Until the Radioactive Substances Act of 1960, the disposal of radioactive waste from non-licensed sites was only subject to the prevailing conventional waste management legislation. The RSA 1960 was enforced from 1963 by the Radiochemical Inspectorate (England and Wales) and HM Alkali and Clean Air Inspectorate (Scotland) (ref 6.2). The Radioactive Substances Act (1993) (RSA 1993) represents the current controlling legislation for the disposal of radioactive wastes.

There is a single dedicated landfill which receives solid low level radioactive waste (LLW). The Drigg site is operated by BNFL and is the only LLW disposal facility in the UK. Disposal options for Intermediate and High Level Waste are under review.

Certain radioactive materials are permitted to be deposited at landfills other than Drigg. Materials classified as Very Low Level Waste, Exempt Waste (as defined by the various Exemption Orders), or Low Level Waste in domestic refuse (eg smoke detectors, some luminescent products) may be able to be accepted at certain landfills, depending on their licence conditions. Low level waste (LLW) was defined by a 1995 White Paper (Cm2919) as containing not more than 4GBq per tonne of alpha or 12GBq/tonne of beta/gamma activity (ref 6.3). Very Low Level Waste (VLLW) was defined by the same White Paper as 'wastes which can safely be disposed of with ordinary refuse – 'dustbin disposal'. Activity limits for VLLW have been defined as less than  $4 \times 10^5$  Bq of beta/gamma activity for each  $0.1\text{m}^3$  of material, or single items which contain less than  $4 \times 10^4$  Bq of beta/gamma activity (ref 6.4).

It is possible that radioactive materials of unknown nature were deposited in landfills prior to the implementation of regulatory controls. Landfills close to areas where radioactive materials

were used (as identified in other sections of this document) are those likely to have the greatest potential for unrecorded radioactive contamination.

### **6.1.2 Sewage Works**

Sewage farms originated during the second half of the 19<sup>th</sup> Century in response to the discovery that many common diseases of the time were water borne and associated with sewage. The early sewage farms spread sewage directly over the land which was then used for agriculture (ref 6.5).

An increase in volumes of sewage brought about the development of sewage treatment works to minimise the volume of sludge for disposal. Modern sewage works involve a staged treatment process which can affect the fate of radionuclides present in the sewage and affect their concentrations in the sewage treatment products.

Radionuclides have historically and are currently discharged into the sewage system under appropriate authorisations by various facilities such as hospitals, universities, research institutes and industry<sup>1</sup>. These authorisations are currently granted by the Environment Agency under the Radioactive Substances Act (1993). In addition, before regulation it is possible that effluents containing radionuclides were discharged to sewers by the industries discussed in other sections. A single sewage treatment works may receive radioactive discharges from a number of facilities.

### **6.1.3 Incinerators**

Incinerators are used to reduce volumes of waste by combustion. They are commonly associated with hospitals, universities and research institutes, since they have the advantage of destroying biological matter present in the wastes (such as pathogens). However such facilities also have the potential for intake of radioactive material in a waste stream and thus generate combustion wastes containing radionuclides.

Incinerators have also been used in the disposal of domestic or municipal wastes since 1876 (ref 6.1). The potential for the occurrence of radionuclides at these incinerators is considered lower than those which serve hospitals etc, but cannot be eliminated due to the historical lack of regulation.

An increasing practice is the incineration of sewage sludge. This is due to the ban on dumping sewage sludge at sea, which was common practice in the UK until 1998. As described above, radionuclides may be present in sewage sludge due to discharges of radioactive effluents to the sewers.

## **6.2 Activities**

### **6.2.1 Landfills**

Controlled landfilling was defined by the Ministry of Health annual report of 1931-32 as the deposition of waste in compacted layers and the application of covering layers of inert materials. Further information on how landfilling practices have changed over time is presented by the existing industry profile (ref 6.1).

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Historically, radioactive materials were not segregated before disposal to landfill, and thus any pre-COPA landfill has the potential to contain radioactive materials. The use of radioactive materials was historically more widespread than at present, for example a cottage luminising industry existed where home-workers would use luminous paints to paint instruments, watches and clocks. Wastes from these activities are likely to have been disposed of along with the domestic refuse.

An example of historic waste disposal practices is given in a report to the Panel on the Disposal of Radioactive Wastes in 1957 which stated that advice had been given in the past to dispose of wastes from luminising works in municipal tips “at least 6ft down” (ref 6.6).

Post-COPA radioactive materials could have been deposited in landfills inadvertently e.g. common place articles such as smoke detectors and certain luminescent materials are not commonly thought of as radioactive. Certain landfill sites can also accept radioactive materials that are exempt from the RSA 1993 or that have been allowed for Special Precautions Burial (SPB). SPB is the disposal of radioactive wastes to a landfill site after an authorisation has been issued by the Environment Agency or SEPA.

### **6.2.2 Sewage Works**

Sewage treatment can comprise up to 4 stages (ref 6.5):

- Preliminary treatment – screening and removal of large objects;
- Primary treatment – sedimentation, producing primary sludge and a liquid effluent;
- Secondary treatment – use of a percolating filter (common in older sewage works) or activated sludge process to digest/breakdown organic material present. Secondary sludge and liquid effluent produced;
- Tertiary treatment – polishing of the liquid effluent – tertiary sludge produced.

The fate of the radionuclides present in the raw sewage will depend upon their partitioning between the liquid effluents and sludges. This can vary from less than 10% to approximately 90% of the total mass of radionuclide being present in the sludge (ref 6.7). The partitioning is influenced by the chemistry of the element itself and the chemical or biological compound it is associated with (radionuclides are rarely used or discharged by hospitals etc in elemental form (ref 6.8)).

### **6.2.3 Incinerators**

The aim of incinerators is to reduce the volume of waste by combustion. There are various designs of incinerator, which will operate at different temperatures. However there are a number of common aspects with regard to the behaviour of radionuclides during incineration. At high temperatures, some radionuclides will be volatilised and either released to air where they will undergo dispersion and deposition, or captured by the off gas scrubbers. The non-volatile radionuclides will remain in the incinerator ash which is usually landfilled. Further details on the behaviour of NORM during combustion processes is presented in Section 13, Coal Fired Power Stations.

## 6.3 Waste Handling

### 6.3.1 Landfills

Landfills are waste disposal facilities and are not usually thought of as generating wastes. However, landfill gas and leachate could be thought of as wastes generated by the landfilling process. Leachable radionuclides present in the body of landfilled wastes may be mobilised during the formation of leachate. In modern engineered landfills, the leachate is commonly collected and monitored before treatment and/or discharge. In older landfills, there is the potential for leachate to dispense to groundwater and thus for radionuclides to migrate off site.

Volatile radionuclides may be associated with landfill gas. Landfill gas is commonly collected and burnt or released at certain points on modern landfills, however the migration of landfill gas either through any capping layer, or off-site is more common in older landfill sites.

### 6.3.2 Sewage Works

Historically, sewage was spread directly on the land at sewage farms, but since the advent of sewage treatment works, waste disposal issues arise concerning both the sludge and the liquid effluent.

The liquid effluent is commonly disposed of to surface watercourses or to sea, and hence any radionuclides which remain in the liquid phase after partitioning will be released into these receiving waters. One study carried out into radioactive discharges to public sewers concluded that the most significant pathway with respect to potential dose to the public is that involving the ingestion of fish from rivers receiving effluents from sewage treatment works which receive radioactive discharges.

Disposal practices for sewage sludge have changed over time, most notably when sea disposal (which was commonly used by works in the east of the UK) was stopped in 1998. The optimum disposal option for sewage sludge is determined by logistics and the content of the sludge. In 1995 44% of sewage sludge was applied to agricultural land, 30% was discharged to sea, 8% was landfilled, and 7% was incinerated (ref 6.8).

The application of sewage sludge to agricultural land is the most common disposal option. This occurs after appropriate treatment of the sludge to reduce risks posed by pathogens, and occurs via spreading or direct injection during ploughing. An associated use of the sludge is its application to derelict land to aid restoration, or to commercial forestry land as a fertiliser.

The proportion of sewage sludge being landfilled is diminishing, from 33% in 1978 to approximately 5% in 2000. Sludges were often co-disposed with municipal wastes to improve the physical characteristics of the waste.

### 6.3.3 Incinerators

Incineration has increased since the sea disposal ban, especially in urban areas where transport costs to rural areas render agricultural application uneconomic. The ash remaining after incineration is usually landfilled and comprises mostly silicic and aluminium oxides, with heavy metals shown to account for less than 0.1% by mass by one study.

Incinerators reduce, but do not eliminate the amount of waste requiring disposal. After incineration, ash containing the non-combustible components of the waste remains. Commonly,

these will include radionuclides associated with heavy metals. The ash is normally landfilled, but has historically been used for construction e.g. for road sub-base. During combustion, off gases are produced which will contain any volatile radionuclides. Any radionuclides associated with small light ash particles may also escape with off gasses. Many modern incinerators have plant such as scrubbers or electrostatic precipitators that will capture either gaseous or particulate radionuclides.

## **6.4 Potential Contaminants**

### **6.4.1 Landfills**

As stated by the existing Industry Profile (ref 6.1), there is the potential for a large range of contaminants to be present at landfill sites. This is as applicable to radioactive contaminants as it is to the conventional chemical contaminants. When evaluating the potential for individual radionuclides to be present in a landfill, the age of the wastes is key since radionuclides with relatively short half lives may have decayed to insignificant concentrations, whilst those with long half lives will persist. The landfill site disposal records will also have details of any radioactive material that is disposed of as exempt waste or under a Special Precautions Burial authorisation.

### **6.4.2 Sewage Works**

As with landfills above, there is the potential for a large range of radionuclides to be present at sewage works and in the effluent and sewage sludge produced. Research into the historical and/or current discharge authorisations in place up stream of the sewage works will help to identify the radionuclides with the greatest potential to be present at a particular site. Likewise information on industrial practices in the catchment area (and identification of any of the other land uses discussed in other sections of this document) will identify key potential contaminants.

Radionuclides discharged to sewers under current authorisations have commonly been used for tracer studies (either medical or industrial), and consequently they often have common characteristics. Tracer radionuclides are often chosen for their ease of measurement, low radiotoxicity and relatively short half life.

A study of two large sewage works (in Leeds and London) identified eight key radionuclides:

- Tritium
- Carbon-14
- Phosphorous-32
- Sulphur-35
- Chromium-51
- Technetium -99m
- Iodine-125
- Iodine -131

In addition authorisations for discharges upstream of the works existed for the following:

- Gallium-67
- Indium-111
- Thallium-201
- Rubidium-83
- Rubidium-84
- Strontium-89
- Yttrium-90
- Iodine-123
- Americium-241

This study also concluded that the concentrations of most of the radionuclides analysed for were below the laboratory limit of detection in the raw effluent, treated effluent and sludge, but were detected in the incinerator cake and ash produced (ref 6.8).

#### **6.4.3 Incinerators**

The potential contaminants at incinerator sites will be dependent on the source of the wastes incinerated. For example an incinerator serving a hospital will have the potential for those radionuclides used in medical applications to be present (details of radionuclides used in medical applications can be found in Chapter 12 of this document). It is the heavier radionuclides which are likely to remain in the ash, whilst those that can undergo volatilisation at high temperatures are likely to be associated with scrubber wastes, or will have undergone atmospheric dispersion and then deposition on the surrounding land.

### **6.5 Significance in the Environment**

The radiological hazards posed by landfills, sewage works and incinerators, will be entirely dependent on the materials disposed of at a particular site. The mechanisms for humans to be exposed to radioactive materials in landfills, sewage work and incinerators is via direct contact with the waste, or from exposure to radioactive leachate from buried wastes.

Landfills, sewage works and incinerators are ubiquitous across the UK, and are often associated with centres of population. The majority of sites are considered likely to pose no/low hazard, however the potential for significant hazards at a small number of sites cannot be discounted. Sites most likely to have received radioactive materials, are those situated near to industrial sites which operated processes described in the other sections of this document.

### **6.6 Relevant Information Sources**

6.1. Department of the Environment (1996) Industry Profile: Waste recycling, treatment and disposal sites. Landfills and other waste treatment or waste disposal sites.

- 6.2. Stearn SM (1993) Reclamation of non-nuclear sites contaminated with radioactive waste: A Regulators view.
- 6.3. Radioactive Waste Management Advisory Committee (2002) Annual Report 2001/2002. [www.defra.gov.uk/rwmac/reports/annrpt0102/13.htm](http://www.defra.gov.uk/rwmac/reports/annrpt0102/13.htm)
- 6.4. House of Lords (1999) – Select Committee on Science and Technology Third Report. [www.parliament.the-stationery-office.co.uk](http://www.parliament.the-stationery-office.co.uk).
- 6.5. Department of the Environment (1995) Industry Profile: Sewage Works and Sewage Farms.
- 6.6. Goodall KL (1957) Panel on disposal of radioactive wastes. Disposal of radioactive waste from factories. HM Chemical Inspector of Factories.
- 6.7. Ham GJ, Shaw S, Crockett GM, Wilkins BT (2003) Partitioning of Radionuclides with sewage sludge and transfer along Terrestrial Foodchain Pathways from Sludge amended Land – A Review of data. NRPB W32. NRPB, Oxford.
- 6.8. Titley JG, Carey AD, Crockett GM, Ham GJ, Harvey MP, Mobbs SF, Tournette C, Penfold JSS, Wilkins BT (2000) Investigation of the Sources and Fate of Radioactive Discharges to Public Sewers. Research and Development Technical Report P288. Environment Agency, Bristol.



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## 7. Luminising Works

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### 7.1 Background

Luminising paints were painted onto scientific, electronic equipment so that they could be read in the dark or with low light. The work was undertaken in luminising workshops, where the dials for such equipment were hand painted using the luminising paint. The paint that was used contained radium, which was mostly manufactured by one firm in the UK, with small quantities being imported (ref 7.1).

The organisations registered under the Luminescing Regulations, 1947, ranged from producers of radium powders/paint, through distributors to instrument and watchmakers and repairers. In the late 1950's, there were thirty seven factories registered under the Luminescing Regulations, to carry out luminising works, of these fourteen were owned by the Ministry of Defence. The Department of the Environment, Transport and Regions (DETR) have identified 12 of the civilian registered sites from government archives (ref 7.1).

More recently promethium-147 and tritium were used in luminising operations.

### 7.2 Activities

The factory that produced most of the radium paint used in the UK was based in East London and also produced thorium salts and rare earth salts as well as a number of organic products. The factory produced radium luminising compound from radium purified at another site (ref 7.2)

Instrument and watchmakers had luminising workshops where the dials of the instrument/watches were painted with the radium luminising compound. A cottage luminising industry was also in operation, with watches and instrument dials being painted by workers at home (ref 7.3).

Contamination of the workshops and surrounding land also occurred, contamination having been identified on the floor and walls of workshops, especially on window sills and radiators where luminised items were left to dry. Drains and sinks also became contaminated from the cleaning of equipment such as brushes (ref 7.4).

Repair and maintenance facilities also became contaminated and produced luminised waste items, although on a much smaller scale than the luminising workshops.

### 7.3 Waste Handling

The radium factory in East London disposed of contaminated material in an on site disposal area, which included radium contaminated material and thorium contaminated material from the production of thorium salts. Organic and inorganic contaminants were also disposed on site. The contaminated materials were either released directly onto the land or buried (ref 7.2).

Waste items from the workshops included empty vials, used brushes, broken dials and other luminised artefacts tended to be disposed of on the site, usually with other wastes produced by the watch or instrument makers. There is also the possibility that the wastes were incinerated prior to disposal as a waste minimisation technique.

Contamination of the land surrounding the workshops is also a possibility with wastes being buried close by or thrown from windows.

There is little information on the disposal practices for waste products from watch and instrument repair workshops.

## 7.4 Potential Contaminants

Radium-226 is a radioactive isotope with a half life of 1600 years. It is a naturally occurring radioactive isotope and is a daughter product from the decay of uranium. Radium is an alpha emitter also releasing some low energy gamma radiation. As radium is an alpha emitter there is only a low risk of a significant dose being received by direct irradiation. The ingestion or inhalation of radium has the potential for a high internal dose to be received by sensitive organs within the body.

Radium contamination on former luminising works and workshops using luminised instruments would have been contained within a non mobile form, with there being little to no leaching to soils and limited solubility within groundwater. Transport of Radium-226 in the ground is most likely to occur by movement of finer sediments in water (eg. run off to drains).

Promethium-147 is a beta emitter with low energy gamma radiation, its half life is a lot lower than that of radium at 2.6 years. Tritium is an isotope of hydrogen, it is a pure beta emitter with a half life of 12.3 years.

## 7.5 Significance in the Environment

The prevalence of luminising sites in the UK is small, with many of the sites having been identified. The contamination of these sites could be significant but would largely be dependent upon their form and function. Contaminants on such sites are alpha and low energy beta emitters, with the main risks from internal doses received via ingestion and inhalation. The hardest sites to identify will be ones used in the cottage luminising industry and there have been cases in the past of garden sheds and rooms in houses being contaminated and containing large amounts of radioactive materials (dials etc).

## 7.6 Relevant Information Sources

- 7.1. Historic and current UK use of radioactive materials, R & D Technical report No P307, Environment Agency 1999.
  - 7.2. Drury NC, Remediation and restoration of a thorium and radium contaminated site, WS Atkins 94.
  - 7.3. Goodhall KL, HM Chemical Institute of Factories – Panel on the Disposal of Radioactive Works (Disposal of Radioactive Work from Factories) Ministry of Labour and National Service 1957.
  - 7.4. Gibbs KJ, Radium contamination. An overview of the Ministry of Defence Experience DRPS 95.
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## 8. Gas Mantle Manufacture

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### 8.1 Background

Gas mantles were invented by Austrian Carl Auer von Welsbach in approximately 1885, and comprised a lighting device which was made from thorium. They were widely used for lighting purposes in domestic dwellings, schools, and for street lamps by 1895. Gas mantle manufacture peaked in the first half of the twentieth century, at a time prior to the strict regulation of waste disposal activities. Gas mantles continued to be in common usage until the mid twentieth century, when alternative sources of light became more widely available (ref 8.1).

The number of former gas mantle manufacturing sites in the UK is unknown, although it is considered likely to be small.

Gas mantles continue to be used for camping lights, however many are now manufactured without using radioactive materials.

### 8.2 Activities

The mantles were made by the impregnation of cloth with nitrate of thorium and other metals (ref 8.1). The fabric was made by the knitting of cotton or silk into a fine cloth, and then saturating it in a lighting fluid which contained thorium salts. The fabric was dried on wood or glass forms before being plaited together to form the mantle. An asbestos cord was drawn through the fabric to form a loop (ref 8.2). When the mantle was heated in a gas flame, the cotton cloth was burnt away and the nitrates decomposed to leave a thin and delicate gauze-like structure which consists mainly of thorium dioxide<sup>1</sup>. The thorium dioxide has a very high melting point (>3000°C) which makes it suitable for use in gas mantles, however the mantle structure is very delicate and requires strengthening by collodion to enable transportation. The collodion burns away during the first use of the gas mantle (ref 8.1).

It is reported that there were five companies engaged in the manufacture of gas mantles during the 1950s. It should be noted that the existence of earlier sites which had closed by the 1950s cannot be discounted (ref 8.3).

### 8.3 Waste Handling

It was common practice in this era to dispose of wastes generated during manufacturing in the most convenient manner, which was often deposition at the manufacturing site. Some landfills were operating during this time, consequently if on-site deposition was not the preferred option, it is possible that wastes from gas mantle manufacture were deposited at landfills. It is known that some areas of the Thorium Ltd site in east London were used for waste disposal (ref 8.4).

Gas mantles themselves are exempted from special regulations governing their disposal, under the Uranium and Thorium Exemption Order (1962) (ref 8.5) which means they could be included with standard waste.

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## 8.4 Potential Contaminants

Waste products from the manufacture of gas mantles have the potential to be contaminated with thorium and its decay products. The principle decay mechanism of thorium 232 is via alpha decay, indicating that the most significant risks to human health will be posed by an internal dose resulting from the ingestion or, inhalation of materials contaminated with thorium. Thorium is considered very immobile, as it is strongly absorbed to soils and sediments, thus it is highly unlikely to migrate and affect other areas.

Individual gas mantles in common usage by the Ministry of Defence were estimated to contain 700-1900 Bq of Thorium-232 (ref 8.5)

### Thorium Ltd

Thorium Ltd operated a gas mantle manufacturing site in east London. In addition to the manufacture of the gas mantles themselves, the extraction of thorium and cerium from monazite sands was also undertaken at the site. Other processes undertaken at this particular site included the production of lanthanum, samarium, praseodymium, neodymium, and yttrium.

Soil samples from the Thorium Ltd site in east London were found to exhibit contamination by Uranium-238 (maximum level identified during a 1987 investigation was 12 bq/g), Thorium-232 (upto 253 bq/g) and a number of other daughter isotopes from the decay of uranium and thorium

Contamination has been identified in areas used for waste disposal and near the rail link used to deliver the monazite sands and remove waste products from the site in east London. Discrete radium sources constituting glass vials containing liquid and pieces of clay-like material were found in shallow soils (ref 8.6). In addition, contamination by a number of non-radioactive heavy metals and acids were also identified on-site, although these may have been related to processes undertaken other than the gas mantle manufacture.

Asbestos was used in the manufacture of gas mantles, due to its heat resistant properties. Therefore the potential exists for asbestos contamination of soils on gas mantle manufacture sites.

## 8.5 Significance in the Environment

Some gas mantle manufacturing sites have the potential to pose significant radiological hazards. For example, Intermediate Level Radioactive Waste was identified at the site in east London. However, the prevalence of such sites in the UK is likely to be limited to a few sites.

## 8.6 Relevant Information Sources

8.1. Essential, useful and frivolous light

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- 8.2. Camden-Cherry Hill West: Environmental Investigation  
[Http://library.thinkquest.org/2654/pages/history.html](http://library.thinkquest.org/2654/pages/history.html)
- 8.3. Department for Environment, Food and Rural Affairs (2001) Historic Practices in the UK which have utilised Radioactive Materials. Report ref DETR/RAS/00.005.  
[www.defra.gov.uk/environment/radioactivity/research/complete/historic/](http://www.defra.gov.uk/environment/radioactivity/research/complete/historic/)
- 8.4. Public Protection Department, London Borough of Redbridge (2003) Personal Communication.
- 8.5. JSP 32, Instructions for Radiation Protection MOD 1999.  
[www.mod.uk/linked\\_files/dsef/hp/jsp392/chap46.pdf](http://www.mod.uk/linked_files/dsef/hp/jsp392/chap46.pdf)
- 8.6. Drury NC (1995) Remediation and restoration of a thorium and radium contaminated site. Radioactive Waste Management and Restoration Vol 19 247-261.



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## 9. Oil and Gas Support Industry

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### 9.1 Background

The oil and gas support industry is the land-based infrastructure set up to support the exploration and extraction of natural oil and gas.

The UK petroleum industry began with the drilling of the first petroleum well in 1859. Oil shales occurring mainly in England and Scotland were used for oil production. Two key areas which were exploited were the Kimmeridge shales of southern England (which were worked from the mid 1800s), and Mid and West Lothian (where activity peaked in the 1870s). The last UK oil shale works closed in 1964. These early industries were mainly in operation prior to the Radioactive Substances Act 1960 and therefore could have resulted in the historical contamination of land. Recent oil and gas production has centred on activities in the North Sea with support from land-based maintenance facilities. The UK is a significant producer of oil and gas, accounting for approximately one third of all gas and in the region of 80% of all oil produced within the European Union. Further information on the oil industry in the UK is presented by the existing series of Industry Profile documents.

Naturally occurring radionuclides are present in varying concentrations throughout hydrocarbon reservoirs which yield the oil and gas used as fuel. The extraction of oil and gas from underground reservoirs mobilises these radionuclides and they are deposited in production equipment and in treatment and transport facilities as Naturally Occurring Radioactive Material (NORM). The association of NORM with oil and gas production was identified many decades ago, however the radiological implications of these activities have only been managed since the early 1980s.

At oil and gas extraction sites, water is pumped into the well to maintain a high pressure and force material to the surface. This water dissolves radium contained within the source rock, and when this water reaches the surface, the radium precipitates out due to changes in temperature and pressure. Radium concentrations are usually highest at the well head, where these changes are greatest. The injection of seawater into the reservoir and subsequent mixing with naturally occurring formation water present may increase the rate of precipitation due to the increased sulphate content.

The radium often precipitates with barium sulphate which constitutes the hard, insoluble scale deposit on drill pipes and extraction plant. Precipitation can also occur with other complex sulphates and carbonates.

### 9.2 Activities

#### 9.2.1 Offshore

NORM associated with oil and gas production include produced water, scales and sludges. Scales were commonly be deposited in downhole assemblies, in the production string and any

equipment above the surface through which wet oil and gas process streams pass, and in the produced water discharge system.

It is reported that hard scales can be deposited at well heads and at the production manifolds, with softer scales formed further downstream, eg in production pipes and vessels. Lead scale, which is observed in gas fields or oil fields with high gas yields, comprises a thin coating, rather than a hard scale. Sludges are deposited in storage tanks, separators and dehydration vessels etc. It is these sludges which contain the majority of the radioactivity associated with NORM in the oil and gas industries.

### **9.2.2 Onshore**

Decontamination facilities exist on-shore for the cleaning of equipment such as pipes, pumps, valves, filters etc which have accumulated scale and are intended for re-use. There are two sites in the UK at Dounreay and Scotoil in Aberdeenshire which are well documented as having carried out decontamination of NORM contaminated equipment, with a smaller third site for which only limited documentation was available. This does not preclude the possible historical existence of others. The items of equipment sent for decontamination are predominantly pipes, but also include manifolds, cooler plates and other components from various fields and platforms. These arrive from offshore installations by ship, and are then transported via road to the de-scaling facilities. During transportation, open ends of tubing are sealed by capping and wrapping with plastic sheeting to prevent escape of any loose NORM.

On arrival at the de-scaling site, the items for decontamination are unloaded into a yard area for assessment. The scales are usually removed by the use of high pressure water jets, which can be located in dedicated buildings, or within controlled open air areas. The stripping down of items of equipment for decontamination (which may include use of hot cutting techniques) may also be undertaken in enclosed or open air conditions.

## **9.3 Waste Handling**

The waste materials generated by the de-scaling operations comprise amounts of scale and waste water containing scale as suspended solids.

At one of the key de-scaling sites in the UK, the scale removed from the equipment is stored in drums, which are disposed of to the BNFL Drigg Low Level Waste Disposal Facility. Scale remaining in suspension can either be allowed to settle out in settling tanks, with the water being recycled back to the jet wash, or the scale is removed via filtration. At one site in the UK, the scale is ground to an appropriately small size, and mixed with seawater, to allow discharge to sea.

With respect to the quantities of scale generated, one UK de-scaling site produced approximately 19,000 kg during 1993 and 26,000 kg, during 1994 with the total activity estimated as approximately 5 GBq and 7 Gbq respectively. The maximum levels of radium-226 and radium-228 in the scales were 220 Bq/g and 170 Bq/g respectively. The other UK de-scaling facility for which information was obtained generated 67,000 kg of scale in 1994, estimated as 19 GBq of activity, with maximum levels of radium-226 and radium-228 being 260 and 160 Bq/g respectively.

### Potential Contaminants

The radionuclides found in wastes from oil and gas production are from the decay series of naturally occurring uranium and thorium. Usually Radium-226 is the dominant radionuclide, however, there are examples from UK gas terminals where the radionuclide being mobilised from the geological formation is nearly exclusively Lead-210.

The typical activities of the various radionuclides present in scale are summarised in the table below, but it should be noted that concentrations of radionuclides in sludges and scales are highly variable due to variations in the nature of the reservoirs and other environmental conditions.

Radionuclide	Typical activity (Bq/g)
Radium-226	200
Lead-210	50
Polonium-210	50
Radium-228	100

Uranium-238 and Thorium-232 can be present in produced waters, but this tends to be in very low concentrations, and is often associated with the presence of suspended clay and sand particles. The relatively low concentrations of uranium and thorium are due to their chemistry, where formation water preferentially dissolves calcium, strontium and radium rather than uranium and thorium.

Radium is slightly soluble (which accounts for the mobilisation within waters during oil and gas production), however the radium containing scales are highly insoluble and therefore do not significantly migrate when released into the environment.

Information on the decommissioning of sites associated with the oil and gas production industries is sparse. Data relating to a site in Croatia details that a dose rate of 0.07 Sv/hr was recorded at the surface of pipelines.

## 9.4 Significance in the Environment

The radiological hazards posed by the oil and gas support industries are considered to be relatively low since there are few land-based sites which handle the NORM sludges and scales. The radionuclides found in NORM scale are predominantly alpha emitters, indicating that risks to humans will be from internal doses resulting from the inhalation or ingestion of materials contaminated by NORM scale.

## 9.5 Relevant Information Sources

9.1. van Weers AW, Pace I, Strand T, Lysebo I, Watkins S, Sterker T, Meijne EIM, Butter, KR (1997) – Current practice of dealing with natural radioactivity from oil and gas production in EU Member States. Final Report Contract No ETNU-CT94-0112. European Communities.

- 9.2. Interstate Oil and Gas Compact Commission – What is NORM?  
[www.iogcc.state.ok.us/norm/dsp\\_what\\_isnorm.cfm](http://www.iogcc.state.ok.us/norm/dsp_what_isnorm.cfm)
- 9.3. Vandenhove H, Bousher A, Jensen PH, Jackson D, Lambers B, Zeevaert T (1999) Investigation of a possible basis for a common approach with regard to the restoration of areas affected by lasting radiation exposure as a result of past or old practices or work activity. Report ref CARE ECDGXI 96-ET-006. European Communities.
- 9.4. Department of the Environment (1995) Industry Profile: Oil refineries and bulk storage of crude oil and petroleum products.

## 10. Breakers Yards

### 10.1 Background

Breakers yards include scrap metal yards, and in more general terms the scrap metal industry. Such yards can vary in size from small businesses to large ship breaking sites

There have been occurrences in Europe (including the UK) where radioactive materials have caused problems within scrap metal sites, and in some cases have resulted in workers being exposed to dose rates in excess of the limits set in the regulations. In other instances the sites themselves have been contaminated which has resulted in remedial measures having to be undertaken.

### 10.2 Activities

Typically scrapyards have been found to contain a range of contaminated materials. Naturally occurring radioactive material (NORM) have been found on tubing from oil and gas exploration and pipe, valves and heat exchangers from the chemical and fertiliser industries. Heavy radioactive industrial sources (such as industrial x-ray sources and thickness gauges) have been found in loads of scrap metal and in some cases radioactive sources have been incorporated into products made from recycled metal.

The table below gives a summary of the incidents that occurred in the Netherlands from 1990 involving the detection of radioactivity in metal and scrap metal (ref 10.1).

Type of radioactive metal object	Number of incidents reported	Country of origin (%)			Specific Activity (Bq/g) or activity (Bq)
		Netherlands	EU	Other	
Tubing on transport containers	Approx 300		95	5	200-5000 Bq/g
Tubing	6	20	30	50	100-2000 Bq/g
Other objects with NORM scale	Approx 60	5	10	85	50-2000 Bq/g
Rockwool	10	100			90-150 Bq/g
Aluminium with thorium (from jet engines)	3			100	800-1100 Bq/g
Objects from the nuclear industry	5		10	90	50-2000 Bq/g
Radioactive sources and source containers	10	10		90	0.5 MBq-20 GBq

Although the above information is not necessarily relevant to the situation in the UK, it gives a general picture of the sources of radioactive materials received by scrap yards. The majority of cases shown above involve objects contaminated by NORM from non nuclear industries. Very few cases involve material from the nuclear industry or industrial sources.

### 10.3 Waste Handling

Many scrap yards now have radiation monitoring devices either at the entrance to the yard, or on the cranes used to move material around (ref 10.2). These allow radioactive materials to be detected prior to them being processed. In cases where radioactive materials are detected the entire load of material is generally returned to the waste producer, thus removing the risk to contamination at the scrap yard.

### 10.4 Potential Contaminants

The radiological hazards posed on breakers yards, will be entirely dependent on the materials disposed of at a particular site. The majority of sites are considered likely to pose no/low hazard, however the potential for significant hazards cannot be discounted.

**Example – Goiania, Brazil (ref 10.3, 10.4)**

A private radiotherapy institute in Goiania, Brazil moved premises in 1985, leaving behind a caesium 137, radiotherapy machine, and scavengers dismantled the machine to sell the parts to a local scrap yard. The dismantling resulted in the source container becoming ruptured. The radioactive source was in the form of caesium chloride salt, which is highly soluble and easily dispersed. The remnants of the source assembly were sold to the scrapyard, the owner of the scrapyard noticed that the source material glowed blue in the dark. Over a next few days friends and relatives came to see this phenomenon which resulted in fragments of the source becoming distributed throughout several families. The accident is classed as the second worst nuclear disaster second only to that of Chernobyl.

### 10.5 Significance in the Environment

Although there are many breakers and scrap yards in the UK there are only a small number that are likely to have received radioactive materials. Incidences in the UK have occurred when contamination of such sites has been extensive and there is the potential for high activity sources to be dispersed. Many operational sites with the potential to receive radioactive materials will have monitoring devices reducing the likelihood that future contamination will occur.

### 10.6 Relevant Information Sources

- 10.1. G.M.Breas and P.I.van der Vaart, Scrapmetals and NORM, 1995;
- 10.2. G.Jonkers and W.A.I. Knaepen, Case Study:Removal of Metal Scrap from a Refinery/Chemical Plant Site. Shell Research and Technology Centre;

- 10.3. Case Study:Accidental Leakage of Cesium-137 in Goiania, Bril, in 1987.  
<http://www.nbc-med.org/SiteContent/MedRef/OnlineRef/CaseStudies/csgoiania.html>;
- 10.4. The Radiological Accident in Goiania. <http://www.-hep2.fzu.cz/~bazalova/Goiania>.



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# 11. Coal-fired Power Plants and Gas Works

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## 11.1 Background

All early power stations built in the UK were coal fired, with many small stations built by local authorities prior to World War One. After this time, electricity generation became more centralised with the building of larger more efficient power stations and the creation of the Electricity Commission which later became the Electricity Board. Large coal power stations were often located near coal mining areas. In 1926 there were 438 coal fired power stations, but the number of individual stations has declined over time to the current 22 stations. This has resulted from centralisation, a tendency for bigger, more efficient stations, and the advent of alternative sources of power such as gas, oil and nuclear power. In 1995 26 of the UK's 86 power stations were coal fire (ref 11.1). Further details of the history of coal fired electricity generation can be found in the existing Industry Profiles.

All coal contains low concentrations of natural radionuclides. The combustion of coal, as in coal fired power stations, releases volatile radionuclides and concentrates non-volatile radionuclides in the resultant ash (ref 11.2)

The existing Industry Profile on Gas Works, Coke Works and other Coal Carbonisation plants (ref 11.3) mentions that uranium oxide was used as a catalyst in a small number of plants.

## 11.2 Activities

### 11.2.1 Coal fired power stations

At coal fired power stations, the coal arrives to site (normally by rail) and is stored in stockpiles directly in contact with the ground. The coal is usually pulverised and blown into the furnace (ref 11.1).

A typical coal fired power station includes a number of units in which pulverised coal is burnt at temperatures between 110 and 1700 °C. Two types of ash are produced from coal combustion:

- Bottom ash - this falls to the bottom of the furnace during combustion, and comprises ash and unburnt coal
- Fly ash (also known as pulverised fuel ash or PFA) – this comprises lighter, smaller particles which escape with the off gases produced during combustion.

The total volume of ash produced and proportion of the two types of ash varies with the type of coal being burnt. The average amount of ash produced is approximately 16% of the volume of coal burnt, but this varies from 1-25 (ref 11.2). The proportion of bottom ash ranges from 10-25% with fly ash at 75-90% of total ash (ref 11.4).

There are three mechanisms which act during combustion to enhance the activity concentrations present in the ash, when compared to those in the coal:

- Radionuclides are not combusted since they are part of the mineral constituent of the coal, and they therefore remain in the ash. Assuming that the average ash content of coal is 16%, the activity is concentrated by a factor of 6.25.
- At high temperatures, volatilisation of some compounds containing radionuclides occurs. These volatiles condense on fly ash particles in the gaseous stream, resulting in higher activities of these particles. This effect is commonly associated with lead and polonium isotopes.
- The activity concentration in ash varies with particle size, which is probably a result of some volatilised compounds condensing more readily on the smaller particles that have a high surface to volume ratio.

These effects are influenced by a number of factors, including type of coal burnt, whether the coal is pulverised before combustion, type of furnace and operating temperature (ref 11.2). The level of enhancement of radioactivity in ash compared to coal can be estimated as up to a factor of ten (ref 11.4).

Apart from ash, there is evidence that radioactivity may be present in enhanced concentrations elsewhere within coal fired power stations. In the Netherlands, scale deposits have been identified on the outside of boiler pipes with activity concentrations of lead-210 in excess of 100 Bq/g. No evidence of these scales has yet been found in the UK, and since the scale formation will depend on the chemical environment and temperature of the boiler, their occurrence in the UK is not certain (ref 11.2).

If the coal fired power station is equipped with flue gas desulphurisation equipment, then enhanced levels of radioactivity may be present in the gypsum which is produced as a by-product (ref 11.4).

When coal fired power stations are decommissioned there is the potential for enhanced levels of radioactivity to be present in structures/ equipment which are contaminated with ash. In particular structures such as the atmospheric release stack may exhibit elevated levels of radioactivity since nuclides in volatile compounds released during combustion may condense on the chimney interior. If demolition materials are recycled, this may result in some materials with enhanced radioactivity remaining on site.

## **11.3 Waste Handling**

### **11.3.1 Coal Fired Power Stations**

Small quantities of the ash generated by coal fired power stations escape to atmosphere whilst the remainder is either deposited in a landfill or used to make construction products. In 1998 a total of 7.4 million tonnes of ash were produced in the UK. 49% of the total UK ash produced was landfilled and 50.6% was sold on, predominantly for use in construction materials.

Ash may accumulate at the power station pending final disposal, or at some stations ash is disposed of on-site eg in above ground landscaped features which are covered with topsoil and vegetation. The largest ash pile found at a power station in the UK was 36m high and had a volume of approximately  $2 \times 10^7 \text{ m}^3$ . There are a number of dedicated coal ash landfills, some of which are operated by the electricity generating companies. When ash is landfilled, it is common practice to remove the topsoil from an area, place a layer of bottom ash (to allow

drainage) and cover with quantities of fly ash. The topsoil is then replaced and planted (ref 11.1). The maximum amount of ash disposed of to a single landfill site in a year was 587,000 tonnes.

In the UK, fly ash is removed from the gas stream by electrostatic precipitators or similar equipment, but nevertheless, approximately 0.4% of the total ash produced escapes to atmosphere. Fly ash can be used in construction materials such as cement, bricks and blocks in addition to its use as construction fill material in roads and embankments. Alternatively the fly ash can be sintered and used as an aggregate. Bottom ash is usually used as aggregate for concrete or in the construction of roads.

## 11.4 Potential Contaminants

### 11.4.1 Coal fired power stations

The principal radionuclides present in coal are from the uranium-235 and thorium-232 decay chains. Due to the age of the coal, these radionuclides are likely to be in secular equilibrium<sup>7</sup>. The activity concentration of coal varies depending upon its type and origin, and can vary as much as 2-3 orders of magnitude. Assuming that decay products are in secular equilibrium with their precursors, it has been estimated that the activity concentration of uranium-238 and thorium is approximately 0.02 Bq/kg.

Table 11.1 (ref 11.2) shows the Uranium-238 and Thorium-232 and Potassium-40 content in coals from different origins.

**Table 11.1 Content in coal from different Origins**

Country	Average Activity Concentration (Bq/g)		
	U-238	Th-232	K-40
Australia	0.03-0.048	0.03	0.04
Canada	0.012	0.007	0.026
China	0.007	0.016	0.03
Germany	0.02	<0.02	-
India	0.024	0.038	0.083
Poland	0.038	0.03	0.29
South Africa	0.03	0.02	0.11
USSR	0.028	0.025	0.12
UK	0.015	0.013	0.15
USA	0.018	0.021	0.052

The activity of various radionuclides has been established in fly ash which has originated from coal of various nationalities. The relevant results are summarised in Table 11.2:

**Table 11.2 Radionuclides in fly ash results**

Radionuclide	Range of activities for UK coal fly ash (Bq/g)	Mean activity for UK coal fly ash (Bq/g)	Mean activity for multinational coal fly ash (Bq/g)
Radium-226	0.072 – 0.105	0.089	0.170
Thorium-232	0.053-0.094	0.068	0.114
Potassium-40	0.8-1.25	0.9	0.652

After Puch et al (1997).

A study carried out on two UK power stations investigated the amount of radioactivity released and concluded that levels of radioactivity in particles from coal fired power stations are insignificant (ref 11.5).

The Environment Agency have commissioned a study of the radionuclide content of ash which is released into atmosphere. The study concluded that lead-210 and polonium 210 are present in enhanced concentrations (by a factor of 1.5 and 2.5 respectively) in relation to uranium-238. Small amounts of potassium-40 are also emitted to atmosphere but these were not considered radiologically significant.

The potential for leaching of contaminants from fly ash is considered to be low, with approximately 2-3% fly ash by mass able to be dissolved in water. Water soluble components within fly ash include metals and sulphates. The leachate generated from fly ash in the UK is normally alkaline. It is considered that there is little environmental impact when fly ash is landfilled or used in the construction of roads. Bottom ash comprises a glassy matrix which is normally considered inert, however some concentrated acids can solubilise its components.

In 1980, it was identified that there is radon emanation from PFA (ref 11.6), indicating that there is potential for some risk to be posed by internal doses to construction workers using these materials.

The activity of gypsum produced by flue gas desulphurisation, has been estimated as 20 Bq/g for radium-226 and thorium-232 by a German study. Another study showed that the activity of gypsum produced by flue gas desulphurisation (estimated as 0.007Bq/g for radium-226) is within the range for natural gypsum (estimated as 0.004-0.030 Bq/g for radium-226).

## 11.5 Significance in the Environment

The information presented above demonstrates that coal ash poses a relatively low radiological hazard, but with in excess of four hundred historical coal fired power stations and coal combustion taking place at numerous other industrial sites, there is the potential for coal ash to be widely distributed throughout the country. The radionuclides present in coal ash decay via

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beta, gamma and alpha mechanisms, indicating that any risks to human health may come from external or internal doses i.e. via inhalation, ingestion, direct contact or proximity to contaminated materials.

## 11.6 Relevant Information Sources

- 11.1. Department of the Environment (1995a) – Industry Profile: Power Stations (excluding nuclear power stations).
- 11.2. Smith KR, Crockett GM, Oatway WB, Harvey MP, Penfold JSS, Mobb SF (2001) Radiological Impact on the UK Population of Industries which use or produce materials containing enhanced levels of naturally occurring radionuclides: Part 1 Coal fired Electricity Generation. NRPB, Oxfordshire.
- 11.3. Department of the Environment (1995b) – Industry Profile: Gas works, coke works and other coal carbonisation plants.
- 11.4. Vandenhove H, Bousher A, Jensen PH, Jackson D, Lambers B, Zeevaert T (1999) Investigation of a possible basis for a common approach with regard to the restoration of areas affected by lasting radiation exposure as a result a result of past or old practices or work activity. Report ref CARE ECDGXI 96-ET-006. European Communities.
- 11.5. Environment Agency (2003) – Radioactive Substances in Yorkshire and the Humber. [www.environment-agency.gov.uk/regions/northeast/412081/1](http://www.environment-agency.gov.uk/regions/northeast/412081/1)
- 11.6. Hoeksema HW (1997) – Radiological consequences of fly-ash in building materials. In Proceedings of International Symposium on Radiological problems with natural radioactivity in the non-nuclear Industry. Amsterdam.

### Additional Information Sources

- 11.7. Puch KH, von Berg W, Keller G (1997) – Radioactivity of combustion residues from coal fired power stations. In Proceedings of International Symposium on Radiological problems with natural radioactivity in the non-nuclear Industry. Amsterdam.
- 11.8. Botezatu E, Iacob O, Clain L, Greca CJ, (date unknown) – Radiation exposure in some non-nuclear involving radioactivity. Romania Institute of Public Health.
- 11.9. Botezatu E (1997) Modified natural radiation exposure as a result of coal used to produce electrical energy. Proceedings of International Symposium on Radiological problems with natural radioactivity in the non-nuclear Industry. Amsterdam.



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## 12. Medical, Research and Teaching Uses

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### 12.1 Background

There are a number of facilities in the UK which are commonly described as ‘small users’ of radioactivity (ref 12.1). These include medical facilities, research centres, teaching institutions and factories. The amount of radioactive materials used by these facilities is often comparatively small.

#### 12.1.1 Medical Facilities

The first medical applications of radioactivity were carried out in France in 1901. The Radium Institute was formed in Paris in 1909 and formed a focus for research into biological /medical uses of radioactive substances (ref 12.2). Nuclear medicine is now practised in numerous hospitals, clinics and dental practices throughout the UK.

There is additional legislation which governs the use of radiopharmaceuticals and sealed radioactive sources, in particular when radioactive substances are administered to or taken in by the body. Three sets of relevant legislation exist under the Medicines Act (1968) and the European Communities Act 1972 (ref 12.3):

- Medicines (Administration of Radioactive Substances) Regulations 1978
- Medicines (Radioactive Substances) Order 1978
- Medicines (Administration of Radioactive Substances) Amendment Regulations 1995

Certificates authorising the administration of radioactive medicinal products are granted by Health Ministers. Separate Research certificates are required for medical research projects involving the exposure of subjects to radioactive substances.

In addition to the above legislation, the Radioactive Substances Act (1993) also applies to medical facilities. However, it should be noted that the Hospitals Exemption Order and Hospitals (Amendment) Order exempts small hospital and clinics from registration and authorisation.

It is worth noting that perhaps the most well known use of radioactivity for medical purposes, X-rays, is unlikely to result in radiologically contaminated land. X-rays are commonly produced using electrical equipment, rather than radioactive sources.

#### 12.1.2 Research and Teaching Institutions

Various universities and research centres have historically and are currently conducting research into radioactive substances themselves, or using radioactive substances to assist in research of other topics. Teaching institutions may also have radioactive materials used in connection with demonstration experiments used for teaching purposes. These are not confined to further or

higher education establishments, but include local schools. Sources used in teaching (especially in schools) are normally only weakly radioactive.

### **12.1.3 Factories**

Small sealed sources are used in factories for gamma radiography, which enables non-destructive internal imaging of products or equipment. Radioactive substances are also used in factories for precision measurement, thickness gauging, static elimination, liquid level controls, package monitors, smoke detectors, fire alarms, calibration systems, and luminous products (ref 12.4).

## **12.2 Activities**

### **12.2.1 Medical Facilities**

The variety of radionuclides used, and the ranges of medical uses has been increasing steadily since the first medical application of radioactivity at the beginning of the twentieth century. Medical uses of radionuclides can be divided into two categories: diagnostic investigations (including for imaging systems) and therapeutic procedures (ref 12.3).

Diagnostic investigations include the use of radioactive tracer substances, which are combined with appropriate chemical compounds so that they are attracted to the organ under investigation. Radioactive tracers often have short half lives or are excreted quickly so that the patient is not exposed to more radiation than necessary. Therapeutic procedures include the use of radioactive substances to treat cancers, and can utilise either sealed or unsealed radioactive sources (ref 12.5).

The UK nuclear medicine survey was carried out in 1993, and identified 235 sites which used radiopharmaceuticals. The survey showed an increase in the number of procedures involving nuclear medicine in the previous 4 years. The vast majority of procedures involving radioactive substances were for imaging purposes (90% in 1993), with the remainder being for non-imaging purposes (7%) or for therapy (3%).

### **12.2.2 Research and Teaching Institutions**

The activities associated with the use of radioactive substances by research and teaching institutions are as varied as the industrial uses identified in other sections of this document. Research has been carried out historically and is on-going into radioactive substances themselves, and their possible uses (either for their radioactive properties, or for other physical or chemical properties not connected with their radioactivity. Several of the industrial uses of radioactive substances have been and are employed in the research of other subjects.

Radioactive sources used for teaching purposes are kept in secure and shielded storage facilities which are not normally accessed by pupils.

### **12.2.3 Factories**

Sources used for modern industrial gamma radiography normally comprised small sealed sources which are usually kept in metal shielding containers which are often designed to double

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as transport containers and therefore comply with the relevant regulations for the transport of radioactive materials (ref 12.6).

A useful historical review of the use of radioactive materials in factories is provided by Goodall, who was HM Chemical Inspector of Factories in 1957, and reported to the Panel on the disposal of radioactive wastes. It was stated that 85% of all radiological materials used in factories at that time comprised sealed sources.

Gamma radiography was the most common use of sealed sources, and this was used to assess castings, welds etc. Radium bombs and occasionally radon were historically used for gamma radiography purposes and these were used at 10 factories according to Goodall.

Static elimination was another widespread use of radioactive materials, e.g. in the textile industry which was strong in Lancashire. The paper making, printing and rubber industries also utilised radioactive static elimination techniques. Nuclear industry facilities at Harwell supplied thallium sources for static elimination, but these were recalled since they were often found to be flaky. A new thallium and aluminium foil was issued as a replacement. Strontium-90 and radium-226 in the form of bonded silver foil were supplied by facilities at Amersham. Some radium-226 ionton static eliminators were imported from the USA. Foil hand brushes were made from polonium 210.

Unsealed sources were nearly all used for luminising works (which are discussed in Chapter 7), but small quantities were used for tracer studies, filter testing and the doping of cold cathode valves etc.

## **12.3 Waste Handling**

### **12.3.1 Medical Facilities**

Radioactivity which has been administered to the body and is excreted will be discharged to the sewage system usually at the hospital. More information on radioactivity and sewage treatment works can be found in Chapter 6 of this document. Hospitals are often served by clinical waste incinerators, thus prior to appropriate regulatory controls on the appropriate disposal of radioactive substances, there was the potential for the incineration of radioactive materials.

### **12.3.2 Research and Teaching Institutions**

It is assumed that similar to other uses of radioactive materials, pre RSA 1960, radioactive materials used by research and teaching institutions were either returned to the supplier (as was sometimes recommended) or disposed of along with municipal wastes.

### **12.3.3 Factories**

It is reported by Goodall that arrangements were in place for the return of many spent sources to facilities at Harwell for re-irradiation when necessary. It is also noted that sources of caesium 137 supplied by Amersham which were not able to be irradiated were supplied with a recommendation that they should be returned to Amersham when spent or no longer required (ref 12.6). Some imported American polonium 210 brushes were sold with instructions to return them to the manufacturer for disposal, however given the distances involved it is unlikely that this was followed.

Goodall also reports advice on waste disposal given to factories undertaking luminising works, which it can be assumed may have applied to other radioactive wastes. This included the placement of wastes in drums for sea disposal, burial in municipal tips at depths of at least 6ft, and burial at the factory site after mixing with concrete. It was common advice to burn the radioactive wastes to reduce their volume, then mix them with concrete before burial. It is reported by Goodall that a firm in Richmond burnt their radioactive waste in an incinerator and then mixed it with their standard wastes which was collected unknowingly by the local authority.

## **12.4 Potential Contaminants**

### **12.4.1 Medical Facilities**

The most frequently used radionuclides (in 1993) identified in the UK nuclear medicine survey were (ref 12.5):

- Technetium 99m
- Krypton 81m (gas)
- Iodine 131
- Xenon 133 gas
- Thallium-201

A comprehensive summary of radionuclides used in nuclear medicine is given by (ref 12.3). A table is presented which details the radionuclide, its chemical form, medical use and approximate normal activity used per procedure.

### **12.4.2 Research and Teaching Institutions**

The range of potential radioactive contaminants for teaching and research institutions covers the whole range of radionuclides. Key potential contaminants should be identified by investigating the nature of the research/teaching carried out at a particular site.

### **12.4.3 Factories**

The small sealed sources used for gamma radiography usually comprise iridium-192, but other radionuclides used include Cobalt-60, Caesium-137, Ytterbium-169 and Thulium-170<sup>4</sup>. Goodall confirms that these radionuclides (except Ytterbium, and with the addition of Tantalum-170 and 182) were also used during the 1950s.

Thallium 204, Strontium-90, Radium-226, and Polonium-210 were commonly used for static elimination, as reported by Goodall.

Goodall also provides selected examples of radiological contamination of factories:

## 12.5 Significance in the Environment

The radiological risks to human health and the wider environment posed by medical facilities, research and teaching institutions and factories will be dependent upon which radionuclides used and the methods of their disposal. These land uses can be considered widespread across the UK, but impacts, if they exist, are likely to be very localised. It is considered that sites which used radionuclides prior to appropriate regulation are likely to pose the highest risks.

## 12.6 Information Sources

- 12.1 Entec UK Ltd and NRPB (1999) – Technical Support Materials for the Regulation of Radioactively Contaminated Land. Research and Development Technical Report P307. Environment Agency, Bristol.
- 12.2 [www.curie.fr/curie/cdrom/present/histoe.htm](http://www.curie.fr/curie/cdrom/present/histoe.htm) what is it?
- 12.3 Administration of Radioactive Substances Advisory Committee (1998) Notes for Guidance on the Clinical Administration of Radiopharmaceuticals and the use of Sealed Radioactive Sources.
- 12.4 Goodall KL (1957) Panel on disposal of radioactive wastes. Disposal of Radioactive Waste From Factories. HM Chemical Inspector of Factories.
- 12.5 Titley JG, Carey AD, Crockett GM, Ham GJ, Harvey MP, Mobbs SF, Tournette C, Penfold JSS, Wilkins BT (2000) Investigation of the Sources and Fate of Radioactive Discharges to Public Sewers. Research and Development Technical Report P288. Environment Agency, Bristol.
- 12.6 NRPB (1992) – Radiation at Work: Industrial Radiography
- 12.7 IAEA (1997) Application of Radiation Protection Principles to the clean-up of contaminated areas. IAEA-Tecd-987. Interim Report for Comment.

