

# Department for Environment Food and Rural Affairs

## Industry Profile

### Industrial Activities Which Have Used Materials Containing Radioactivity

March 2006



The purpose of this publication is to provide regulators, developers, consultants and other interested parties with advice on the likely occurrence of radioactive contamination resulting from certain industrial activities. This publication 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. Defra can not accept liabilities resulting from the use or interpretation of the contents of this publication.

Defra wishes to acknowledge the work of Entec and Atkins in the preparation of this Industry Profile.

# 1. INTRODUCTION - PURPOSE OF THE INDUSTRY PROFILE

This Industry Profile provides local authorities, owners, developers 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 that may result in radioactive contamination. It is not a definitive study but introduces some of the technical considerations that need to be borne in mind at the start of an investigation for possible land contamination.

All the individual industry data sheets found in this profile should be read with the following reservations in mind:

- Individual sites will not necessarily have all of the characteristics described in the sheet for that industry or land use;
- Practices can vary between sites and change over time;
- As practices change, problems associated with possible contamination may also change;
- The data sheets may refer to practices that are no longer followed but which may previously have resulted in radioactive contamination, and may omit current practices that avoid contamination.

The current profile is believed to include all of the major industries and land uses associated with radioactive materials. However, it is recognised that there may be others which could have lead to radioactive contamination. The data sheets are presented in a 'modular' format such that additions can be made at as new information comes to light.

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

For many industries or activities it is possible that both chemical and radioactive contamination may have occurred. In these cases, it is essential that both the data sheet dealing with the radiological activity and any others relevant to the historical land-use in the Industry Profile series are consulted if a site is to be adequately assessed.

## **2. GENERAL CIRCUMSTANCES WHERE RADIOACTIVE CONTAMINATION OF LAND MAY HAVE OCCURRED**

Historical contamination of land by radionuclides from anthropogenic activity 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 start of the twentieth century, but most have only been subject to regulation since 1963, the year in which the 1960 Radioactive Substances Act came into force. Industrial activities have involved the use of materials containing radioactivity in a variety of different contexts:

- Where radioactive materials have been employed for their radioactive properties (for example, luminising works);
- Where radioactive materials are incidental to materials that are used for their non-radioactive properties (for example, gas mantle production); and
- Where radioactive materials have been inadvertently handled, or escaped accidentally (for example, lead mining).

Some industries will therefore have been aware of the hazards associated with the radioactivity and applied the controls in place at the time, whilst others are likely to have been unaware of the hazards, and will have 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 activities will have been deposited at some sites.

## **3. THE REGULATORY FRAMEWORK**

### **The Contaminated Land Regime**

Part 2A of the Environmental Protection Act 1990 (EPA 1990) - which was inserted into that Act by section 57 of the Environment Act 1995 – came into force in England on 1 April 2000 to help deal with the historical legacy of contaminated land. It focuses on the identification and remediation of land which is in such a condition by reason of contamination that it gives rise to significant harm or the significant possibility of significant harm to certain named receptors (human beings and the wider environment), or gives rise to pollution of controlled water or the likelihood of such pollution. Similar regimes are in place in Scotland and Wales. Harm and the significant possibility of harm to human receptors where attributable to radioactivity is to be included in an extended regime in Summer 2006.

The regime only applies to the current use and the relevant circumstances of the land. It is not directed at assessing risks in relation to a future use of the land that would require a specific grant of planning permission.

The Part 2A approach is based upon the principles of risk assessment, including the concept of a contaminant, a receptor and a pathway, which, if combined, form a pollutant linkage. The existence of a significant pollutant linkage forms the basis of a formal determination that land is contaminated land. Further details of the regime can be found in DoE Circular 02/2000 'Contaminated Land'

<http://www.defra.gov.uk/environment/land/contaminated/circ2-2000/index.htm>

This profile will principally be used to provide information on land-uses which might fall within the scope of the Part 2A regime. **It should be noted that this profile provides information on the source only.** The threshold criterion for a formal determination, in cases of harm relating to lasting exposure, has been set at an individual effective dose of 3 millisieverts/year above local natural background.

This profile will also provide useful data to support remediation projects carried out under planning legislation (for which the dose thresholds are significantly lower - by one order of magnitude - than the 3 millisieverts/year used in the context of the Part 2A regime).

## **The Radioactive Substances Act**

The primary aim of the Radioactive Substances Act 1993 is to ensure the control of radiation exposure resulting from radioactive wastes entering the environment. This is achieved through the application of a prior permission regime which 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 wider environment.

The Act is administered by the Environment Agency in England and Wales; the Scottish Environment Protection Agency in Scotland and the Environment and Heritage Service in Northern Ireland.

The Radioactive Substances Act came into force in 1963 and was consolidated in 1993. Prior to 1963, controls on radioactive wastes were less stringent. For this reason, many of the data sheets in this profile make reference to an increased likelihood of radioactive contamination being generated prior to 1963.

Exemption orders are statutory instruments made under the Act and specify classes of premises, undertakings or persons, and radioactive material or radioactive apparatus that do not need to be registered or further authorised. The orders are a mechanism for providing a degree of control, without excessive bureaucracy, over minor uses of radioactive substances where there is a clear benefit from its use, whilst ensuring continued protection of the environment and the public.

## 4. INTRODUCTION TO RADIOACTIVITY AND TERMS USED IN THIS PROFILE

A general description of radioactive phenomena is provided in Annex A. This section constitutes a brief introduction to the phenomena and to the terms used in this profile.

### **Radioactivity**

Radioactivity is a property possessed by radioactive substances of spontaneously emitting energetic particles and energy rays from the disintegration of their atomic nuclei. This process is known 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.

### **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.

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

These are high speed electrons that are emitted from the nucleus of an atom.

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

Gamma radiation is a form of electromagnetic radiation emitted from the nucleus of an atom and is often emitted with alpha and beta particles. Gamma radiation is uncharged, has no mass and travels at the speed of light.

### **Radioactive Half-Life**

The time taken for the activity of a radionuclide to fall to half its original value is called the half-life.

### **Radiation Dose**

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, with a greater dose representing a higher risk of harm caused by the radiation. There are three ways of describing radiation dose:

- The absorbed dose which is the measurement of the energy that is deposited in a material per unit mass from any interaction with radiation. It is measured in grays (Gy) with 1 gray equal to 1 joule per kilogram.
- The equivalent dose which is the absorbed 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. It is measured in sieverts (Sv).

- The effective dose, is the sum of the weighted equivalent doses. The weighting takes into account the differing sensitivities of different organs. This allows the various dose equivalents in the body to be represented as a single number. This dose provides a broad indication of the detriment to health from any exposure to ionising radiation. It is measured in sieverts (Sv).

### **Exposure Pathways**

There are two main exposure pathways of an individual to radiation: exposure from external radiation; and internal exposure after an individual has ingested or inhaled radioactive material. The magnitude of the dose depends on:

- 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.

### **Radiotoxicity**

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

- The type of radioactive emissions – alpha, beta, gamma;
- The radioactive half-life of the radioactive substance;
- The biological half-life – a measure of the time the radioactive substance will be resident in the body;
- The location of the radioactivity – some radionuclides concentrate within specific organs and tissues within the body; and
- The sensitivity of targeted organs to damage by irradiation.

### **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 outer space, radioactive elements naturally present in rocks and soils and in the food and drink that we eat. This natural background radiation is not usually considered when taking steps to reduce radiation exposure. All life forms have always been exposed to it, and furthermore, reductions are not generally practicable

### **Naturally occurring radioactive material (NORM)**

NORM is radioactive material which is naturally present in the earth's crust, and has not resulted from any anthropogenic activity such as weapons testing or energy production. Many activities described in the data sheets have had the effect, not of generating new radioactive material, but of concentrating naturally occurring radioactivity to a level higher than that found naturally.

## 5. INDUSTRY PROFILE STRUCTURE

The information in this profile is presented as a series of data sheets, each dealing with an industry which is known to have employed radioactive materials. The sheets consider both non-natural and enhanced natural sources of radioactive contaminants, with the potential to be found in the environment. They are organised into a number of industry groups with the potential to be associated with radioactive contamination. The industry groups are:

- [Group A](#): *Metals (mining and refining) industry*;
- [Group B](#): *Ministry of Defence and associated activities*;
- [Group C](#): *Energy industry*;
- [Group D](#): *Waste management industry*;
- [Group E](#): *Miscellaneous industries and other activities*.

The identification of a land use in these data sheets does not imply that radioactive contamination will necessarily exist at such a site. Nor does it imply that a source-pathway-receptor is in place in every case.

Each data sheet considers key issues under the following headings:

- Background – which provides context and explanation, where available, of how radionuclides may occur in such industries;
- Activities – which looks in more detail at the industrial activities that have taken place on such sites and how they may have used radionuclides directly or inadvertently;
- Waste management – which deals with the wastes arising from the industrial activities, and the implications for the presence of radioactive contamination on such sites;
- Potential contaminants – which considers briefly the main radionuclides and their properties which may be expected at such sites;
- Prevalence and potential impacts – which attempts to set the scale of the possible contamination in context by reference to the possible extent of the industry, the likely severity of risk arising from the particular radionuclides, and the probability of occurrence of contamination; and
- Implications for the Part 2A regime – in which the potential sources of radioactive contamination are summarised in terms of the likelihood that the source in question is capable, given the presence of a pathway and a receptor, to give rise to an effective dose to a human receptor of 3 millisieverts/year or greater above local natural background levels. (Each data sheet contains one of two phrases ‘unlikely to be capable of’ or ‘capable of giving rise to’, to reflect this likelihood). This excludes doses from radon.



## 6. DATA SHEET SUMMARY TABLE

Data Sheet	Industry	No. of sites (range)	Key Radionuclides and main pathways	Potential for an effective dose >3millisieverts/year
<a href="#">A1</a>	Uranium mining	1-10	Uranium and thorium and decay-chain daughters (including radium-226). Airborne dusts from waste heaps → ingestion or inhalation	Capable, but only where slag heaps disturbed and high occupancy occurs
<a href="#">A2</a>	Metals mining	100 – 1000	Uranium and thorium and decay-chain daughters (including radium-226). Airborne dusts from waste heaps → ingestion or inhalation	Unlikely
<a href="#">A3</a>	Tin refining	10-100	Uranium and thorium and decay-chain daughters (including radium-226). Airborne dusts from waste heaps → ingestion or inhalation	Unlikely
<a href="#">A4</a>	Copper refining	10-100	Uranium and thorium and decay-chain daughters (including radium-226) Airborne dusts from waste heaps → ingestion or inhalation	Unlikely
<a href="#">A5</a>	Aluminium refining	1-10	Thorium-232 and thorium decay-chain daughters. Airborne dusts from waste heaps → ingestion or inhalation	Unlikely

<a href="#">A6</a>	Ferrous metals refining	100-1000	Uranium and thorium and decay-chain daughters (including radium-226). Lead-210 and polonium-210 detected in dusts  Airborne dusts from waste heaps → ingestion or inhalation	Unlikely
<a href="#">A7</a>	Lead refining	10-100	Uranium and thorium and decay-chain daughters (including radium-226).  Airborne dusts from waste heaps → ingestion or inhalation	Unlikely
<a href="#">A8</a>	Zinc refining	10-100	Uranium and thorium and decay-chain daughters (including radium-226).  Airborne dusts from waste heaps → ingestion or inhalation	Unlikely
<a href="#">A9</a>	Rare earth metal refining	1-10	Radium-226 and radium-228.  Airborne dusts from waste heaps → ingestion or inhalation	Capable
<a href="#">B1</a>	Radium luminising works	10-100	Radium species.  Ingestion of contaminated material.	Capable
<a href="#">B2</a>	Depleted uranium munitions manufacture and testing	0-10	Uranium-238.  Ingestion or inhalation of uranium dusts or fine particles.	Unlikely
<a href="#">B3</a>	MOD burning grounds	10-100	Radium species.  Ingestion of contaminated material.	Capable, but only in the case of radium contamination (see

				B1)
<a href="#">B4</a>	MOD maintenance facilities	10-100	Radium species, thorium species, Promethium-147 and tritium.  Ingestion of contaminated material.	Capable, but only in the case of radium contamination (see B1)
<a href="#">C1</a>	Oil and gas facilities	10-100	Uranium and thorium and decay-chain daughters (including radium-226).  Airborne dusts from wastes heaps → ingestion or inhalation	Unlikely
<a href="#">C2</a>	Coal-fired power stations	100-1000	Uranium and Thorium and decay-chain daughters (including radium-226).  Airborne dusts from wastes heaps → ingestion or inhalation	Unlikely
<a href="#">C3</a>	Gas industry (historical)	100-1000	Uranium species.  (No significant pathways)	Unlikely
<a href="#">D1</a>	Landfill sites	1000-10,000	Any, but tritium has been detected more frequently and in higher concentrations than other species.  Inhalation or ingestion of airborne or water borne tritium compounds.	Capable, but only in some circumstances e.g. old closed landfills in a region containing industries which have produced and disposed of radioactive wastes prior to 1963
<a href="#">D2</a>	Sewage works	100-1000	Short-lived beta gamma emitters.  Ingestion of foodstuffs grown on land on which sewage sludges have been deposited.	Unlikely

<a href="#">D3</a>	Incinerators	10-100	Short-lived beta gamma emitters, tritium and carbon-14.  Deposition of airborne contaminants and ingestion of foodstuffs grown on the area of deposition.	Unlikely
<a href="#">D4</a>	Scrap recycling	1000-10,000	Any.  (No significant pathways)	Unlikely
<a href="#">E1</a>	Phosphate industry	10-100	Uranium and thorium and decay-chain daughters (including radium-226).  Airborne dusts from waste heaps → ingestion or inhalation	Unlikely
<a href="#">E2</a>	Gas mantle production	1-10	Thorium species and thorium daughters.  Airborne dusts from wastes → ingestion or inhalation	Capable
<a href="#">E3</a>	Medical establishments	100-1000	Mainly short-lived beta gamma emitters.  (No significant pathways)	Unlikely
<a href="#">E4</a>	Miscellaneous small users	1000-10,000	Any.  (No significant pathways)	Capable, but only in cases of premises prior to 1963 using open sources which were disposed of locally
<a href="#">E5</a>	Nuclear industry	10-100	Uranium and plutonium species, tritium and fission products.  Direct radiation from contaminated areas, or use of materials from contaminated areas.	Unlikely

## 7. SUMMARY INFORMATION ON RADIONUCLIDES IDENTIFIED IN THE DATA SHEETS

Radionuclide	Main Daughter Isotopes	Principal Decay Mode	Half-Life	Comments
<b>Carbon-14</b>	Nitrogen -14	Beta	5,730 yr	Low energy beta emitter widely distributed throughout terrestrial and aquatic environments.
<b>Caesium-137</b>	Barium-137	Beta (gamma)	30 yr	Binds strongly to clays but available for plant uptake.
<b>Chromium-51</b>	Vanadium-51	X-ray	27.7 d	Emits gamma rays in 10% of transformations. Low bioavailability.
<b>Cobalt-60</b>	Nickel-60	Beta (gamma)	5.27 yr	Decay in-situ as retained in soils and sediments.
<b>Depleted Uranium</b>		Alpha	4.46 x 10 <sup>9</sup> yr	Not strongly absorbed in soils but may be mobile, if released to atmosphere in the form of uranium compounds such as oxides and fluorides.
<b>Iodine-125</b>	Tellurium-125	X-ray	59.4 d	Also releases low energy photons. Concentrates in thyroid of animals.
<b>Iodine-131</b>	Xenon-131	Beta (gamma)	8.02 d	Will migrate via surface and groundwater. Concentrates in thyroid of animals.

<b>Radionuclide</b>	<b>Main Daughter Isotopes</b>	<b>Principal Decay Mode</b>	<b>Half-Life</b>	<b>Comments</b>
<b>Iridium-192</b>	Platinum-192	Gamma	73.8 d	Only limited research into environmental fate.
<b>Promethium-147</b>	Samarium-147	Beta	2.6 yr	Will remain bound to soil particles, surface of plants and sediments.
<b>Radium 226</b>				
<b>Sulphur-35</b>	Chlorine-35	Beta	87.3 d	Will accumulate in plants and animals and will distribute equally throughout.
<b>Strontium-89</b>	Yttrium-89	Beta	50.5 d	High bioavailability.
<b>Technetium-99</b>	Rubidium-99	Beta	2.1 x 10 <sup>9</sup> yr	Low energy beta emitter of high bioavailability.
<b>Thorium-232</b>		Alpha	1.14 x 10 <sup>10</sup> yr	Very immobile as strongly adsorbed to soils and sediments.
	Radium-228	Alpha	5.8 yr	
<b>Tritium</b>	Helium-3	Beta	12.4 yr	As hydrogen is a constituent of all tissues, no specific organs will accumulate.
<b>Uranium-235</b>		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.

Radionuclide	Main Daughter Isotopes	Principal Decay Mode	Half-Life	Comments
	Actinium-227	Beta	21.6 yr	Rarely encountered.
	Thorium-227	Alpha	18.7 d	Remains in-situ in soils and binds to sediments in aquatic systems.
	Radium-223	Alpha	11.7 d	Rarely encountered.
<b>Uranium-238</b>		Alpha	$4.47 \times 10^{10}$ 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	$2.45 \times 10^5$ yr	As Uranium-238.
	Thorium-230	Alpha	$7.7 \times 10^4$ yr	As Thorium-234.
	Radium-226	Alpha	1600 yr	Most natural radium-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.





## [DATA SHEET NUMBER A1: URANIUM MINING](#)

### [\(back to Group A\)](#)

#### 1. Background

Uranium was historically mined in a few locations in the South West of the UK. Uranium was used for both its radioactive and non-radioactive properties. Early mining activities were concerned with the non-radioactive properties of uranium which was used in the glazing of pottery. The major user being the Potteries area of Staffordshire. UK mines also mined uranium ore for the production of radium (a uranium daughter isotope), which was generally used for its radioactive properties. There are believed to be only a very few closed uranium mines, all on a relatively small scale, and most located in SW England.

Use of uranium in pottery glazes was in such low quantities and concentrations that there are not believed to be any potential contamination issues related to pottery works.

#### 2. Activities

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. Ore was dug and crushed on-site. In some locations the uranium ore was processed on the same site.

#### 3. Waste Management

Waste rock was the main waste product from the mining of ores. It was often stored on the site in a spoil heap and accompanied by other (non-active) wastes. On sites where ore processing has also been undertaken, the spoil heap can also include waste sludges and slags.

Sizes of the spoil heaps are largely dependent on the size and form of the mining operations. In some cases, spoil will have been used to infill valley features adjacent to the deeper mines. The location of stockpiles or deposits of waste materials vary from site to site, depending upon land availability, topography and other local factors.

Some of the abandoned sites will have been greatly disturbed due to reprofiling and/or re-mining, with spoil being removed and used elsewhere.

#### 4. Potential Contaminants

Uranium does not immediately decay to a stable element. Its decay results in other radioactive materials, some of which are of radiological significance in their own right, such as radium. The mining and processing required to produce uranium metal removes the majority of the decay products from the uranium. These decay products are preferentially concentrated in the tailings and must be taken into account when considering the potential impacts of uranium mining.

Uranium mining could have resulted in the contamination of slag heap areas by elevating concentrations of naturally occurring radioactive material (NORM). Studies of the uranium mining industry in the former East Germany have shown that wastes of barren rock contained uranium concentrations with a total activity of 2 to 5 Becquerels/gram (Bq/g). Cut-off grade rock had a higher uranium concentration with a total activity of approximately 30 Bq/g. No corresponding data has been found for the few mines known to have existed in the South West of England, but it is probable that concentrations would be in the same orders of magnitude as those overseas. These levels (~ 30Bq/g) are such that the material would be considered to be 'radioactive' under the terms of the Radioactive Substances Act; that is, that the wastes would be classified as 'radioactive waste'.

## 5. Prevalence and Potential Impacts

The mining of uranium has not been carried out in the UK for over a century and not all of the sites are believed to have been identified. The total number of identified sites is five, all of which are limited to the South West of England. Although many of the mines were small in scale, the associated spoil heap could be a considerable size and it is unlikely that the disposal of waste would have been under any control, as all activities pre-date the introduction of the Radioactive Substances Act in 1963.

Uranium mine wastes are likely to contain activity concentrations of radionuclides that would class them as 'radioactive' in line with the Radioactive Substances Act. The main exposure pathway from uranium is by ingestion and inhalation, or injection through wounds, which could result in a high internal dose being received.

When assessing potential doses from uranium, the daughter isotopes should also be considered. Some of these are gamma emitters and there is therefore a small risk of direct radiation. The main contaminant exposure pathway to human receptors from uranium daughters is also from the inhalation or ingestion of dust containing radionuclides, the most important radioisotope in this pathway being radium-226 due to its high radiotoxicity. Older spoil heaps tend not to generate great amounts of dust as they have a vegetation barrier; this exposure pathway is likely to be limited to times where disturbance of the spoil would increase the generation of dust.

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 slightly elevated radionuclide concentrations, and there have been cases near to uranium mines, where there has been a build up of radium within fauna and flora. Undisturbed sites have become the habitat for some rare-metal tolerant plant species, and consequently any remediation of such sites needs to be appropriately justified and optimised taking account of the presence of rare species.

## 6. Implications for the Part 2A Regime

The concentrations of both uranium and uranium daughters in uranium mining residues, although low, are **capable of giving rise** to an individual effective dose of 3 millisieverts/year above local natural background levels. However, this is only likely to occur in situations where there is deliberate disturbance of the land, accompanied by high occupancy times.

## 7. References and further information

David Wickers et al, Survey of derelict land in England. HMSO. 1993.

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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.

Environment Agency, Defra, Welsh Assembly Government. Indicators for land contamination. 2005.

<http://publications.environment-agency.gov.uk/pdf/SCHO0805BJMD-e-e.pdf>

## DATA SHEET NUMBER A2: METALS MINING

### 1. Background

Mining activities were historically carried out in strata that had deposits of naturally occurring radioactive materials (NORM), with varying amounts of uranium, thorium and daughter isotopes. No metals mining is currently undertaken in the UK on an industrial scale.

**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 of England. Such mining grew from around the twelfth century until the eighteenth century, when many of the uses of copper and tin were replaced with iron.

**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 were located in Cumbria, the North East, Yorkshire and the Midlands. Mining for iron ore began with the use of bottle necked or bell pits, but these only produced small quantities of iron ore before the pits flooded. The improvement in mining techniques and the use of engineered drainage in the 1700s greatly increased the production of both iron and coal.

The most common **lead ore** found in the UK was Galena (lead sulphide) which occurred in association with minerals such as quartz, fluorspar, calcite and barytes. Lead was often co-mined with tin. Lead and tin have been mined in the UK since Roman times, with production increasing between the thirteenth and sixteenth centuries due to their demand for use in the construction industry. They became important again at the beginning of the nineteenth century during the industrial revolution. Lead and tin mines were distributed throughout the UK, with mines found in Scotland (Dumfries and Galloway), Wales, Northumberland, Durham, Yorkshire, Derbyshire, Shropshire and Cornwall.

The mining of **zinc ore** was also historically carried out in the UK. Zinc was very rarely mined alone; it often accompanied lead mining. Historical records show that the greatest number of zinc producing mines in the UK were active around the 1900s. 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, both of which also mined lead.

### 2. Activities

In metal mining activities, materials are mined for their non-radiological properties. The ore is extracted and crushed ready for transport and subsequent extraction. In some cases, extraction processes may have been carried out locally. The practice

lead to the generation of spoil heaps and occasional sludges with elevated concentrations of NORM.

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.

### 3. Waste Management

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

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

Some of the abandoned sites will have been greatly disturbed due to reprofiling and/or re-mining, with spoil being removed and used elsewhere. Undisturbed sites have become the habitat for some rare metal tolerant plant species, and consequently any remediation of such sites needs to be appropriately justified and optimised taking account of the presence of these rare species.

Radioactive concentrations in the feed materials (the original ore) for different metal industries are generally very low. The refining and smelting process produces slag which, in some cases effectively concentrates the radionuclides, leading to elevated activity. Wastes from the tin industry do produce slightly higher concentrations of NORM than the other metal industries. The location of stockpiles or deposits of waste materials will vary from site to site, depending upon land availability, topography and other local factors.

### 4. Potential Contaminants

Metalliferous mining wastes can contain higher than normal concentrations of NORM contaminants.

Soils and spoils of metalliferous mining sites and the surrounding area may also contain considerably elevated concentrations of other (non-radioactive) heavy metals. The extent of such contamination – both radioactive and non-radioactive - within and between sites may vary considerably. On sites where ore processing and smelting has taken place alongside mining, spoils can contain deposits with up to 50% total metals, whereas on sites where only barren rock has been discarded, total metal levels may be barely above background.

Tin slag is a very hard, glassy material and has been extensively used in the rail industry to improve drainage under ballast when laying tracks. The radioactive content of such slag is at a level that the material has to be considered under the

Radioactive Substances Act. This creates waste disposal issues for the removal of rubble and ballast from old railway lines.

#### 5. Prevalence and Potential Impacts

The number of former metalliferous mines is large and they are distributed around the whole of the UK. The majority of these mines were small in scale and operated when there was no control on the use of radioactivity or waste disposal. Many of these mines have closed and some remain unidentified. The presence of elevated levels of NORM in the mining wastes is possible on such sites.

The main contaminant exposure pathway to human receptors is from the inhalation or ingestion of dust containing radionuclides, the most important radioisotope in this pathway being radium-226 due to its high radiotoxicity. Due to the age of the mines – most have been closed since the early decades of the twentieth century – any spoil heaps remaining are likely to be covered with vegetation, thus providing a barrier to migration for uptake via the ingestion or inhalation pathways. Furthermore, many of the slags are in the form of a highly insoluble glass, thus restricting environmental transport in, say, groundwaters.

The main environmental pathway is from the leaching and transport of radium-226 from spoil heaps, although the solubility of radium is low. 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 metals mines often have slightly elevated radionuclide concentrations, and there have been cases near to such mines, where there has been a build up of radium within fauna and flora.

#### 6. Implications for the Part 2A Regime

The concentrations of NORM are slightly elevated in spoil heaps associated with metalliferous mining such that they are **unlikely to be capable of** giving rise to an individual effective dose of 3 millisieverts/year above local natural background levels.

## 7. References and further information

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 as a result of past or old practice or work activity. Report ref CARE ECDGXI 96-ET-006. European Communities. 1999.

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Harvey et al. Radiological Consequences of Waste Arising with Enhanced Radioactivity Content from Special Metal and Ceramic Processes. European Commission. 1994.

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Indicators for Land Contamination. Environment Agency, Defra, Welsh Assembly Government. 2005.

<http://publications.environment-agency.gov.uk/pdf/SCHO0805BJMD-e-e.pdf>

## DATA SHEET NUMBER A3: TIN REFINING

### 1. Background

Currently in the UK the majority of tin is produced from recycled sources, with less than 25% coming from mined ores. However, slightly contaminated radioactive wastes in the slags can occur during the refining process, since the processing steps (smelting) can concentrate naturally occurring radioactive materials (NORM) already present in the metal ore. Refined tin is used in alloys and as a protective coating for other metals.

### 2. Activities

Tin ores often occur with other metals, primarily lead. Tin rich residues and ores are smelted under hot reducing conditions to produce a molten metal stream. This is then separated into tin, lead, bismuth and lead/bismuth alloy.

### 3. Waste Management

During the smelting process waste gases are released in the furnace. Slags are produced within the blast furnace. The smelting process also produces a dross consisting of tellurium oxide. Many sites had slag piles and slurry lagoons, with some sites also having their own landfill areas.

### 4. Potential Contaminants

Uranium-238 and thorium-232 are associated with tin ores; in addition, unfiltered atmospheric releases (fume release during the smelting process) have been shown to contain approximately 200 Becquerels/gram (Bq/g) of polonium-210 and low levels of lead-210. Although this figure is significant for polonium, atmospheric releases on this scale are unlikely to cause land contamination to any significant degree.

Slags can contain approximately 4 Bq/g of thorium-232 and 1 Bq/g of both uranium-238 and radium-226. These values are such that they are outside the requirements of the Radioactive Substances Act.



## 5. Prevalence and Potential Impacts

The UK has a long history of tin processing up to the present day 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. These may be hard to identify due to the lack of documented history.

The slag has often been used in the road construction industry as an aggregate and because it is a very hard, glassy material it has been extensively used in the rail industry to improve drainage under ballast when laying tracks.

Tin slags contain only low concentrations of radionuclides and so will have a very limited radiological impact on the environment.

The majority of the radionuclides present in the wastes are alpha emitters with some low energy beta emitters. The main problem from these waste areas is the production of contaminated dusts. If these become airborne they can increase the possibility of ingestion or inhalation by humans or animals as well as causing the migration of contamination. The main pathway for human dose uptake is therefore from internal doses received from the ingestion or inhalation of contaminated materials.

The main environmental pathway of concern is for radium-226, which may leach from the waste heaps and migrate via groundwater, although solubility is low, and even lower in the case where it is contained within glassy tin slag.

## 6. Implications for the Part 2A Regime

Concentrations of radioactive contaminants in tin slags are such that they are **unlikely to be capable of** giving rise to an individual effective dose of 3 millisieverts/year above local natural background levels under any reasonable scenario.

## 7. References and further information

David Wickers et al. Survey of derelict land in England. HMSO. 1993.

General State of Industry – Tin Mines. <http://www.history.rochester.edu/steam/lord/2-3.htm>

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 as a result of past or old practice or work activity. Report ref CARE ECDGXI 96-ET-006. European Communities. 1999.

Indicators for Land Contamination. Environment Agency, Defra, Welsh Assembly Government. 2005.

<http://publications.environment-agency.gov.uk/pdf/SCHO0805BJMD-e-e.pdf>

## DATA SHEET NUMBER A4: COPPER REFINING

### 1. Background

The UK has a long history of copper refining with a large number of historical sites located around the UK. The greatest risk of contamination problems is from sites that were operational prior to the regulation of waste disposal under the Radioactive Substances Act in 1963. These may be hard to identify due to the lack of documented history.

### 2. Activities

The ore is prepared by crushing it into a fine powder followed by the addition of water and chemical reagents to form a slurry. Air is blown through the slurry in a flotation cell, copper minerals become attached to the air bubbles and float to the top, where they are skimmed off.

Dependent upon the ore type, copper can either be produced pyrometallurgically (smelting) or hydrometallurgically (leaching). If the ore concentrate is predominantly made up of copper and iron sulphides, it is treated pyrometallurgically. Hydrometallurgical processes are used for ore concentrates that are dominated by copper oxide minerals and can also be used for oxidised waste products.

The smelting process dries the concentrated ore within a furnace. This causes the sulphide minerals to partially oxidise into a 'matte' (a mixed copper and iron sulphide) with a 'slag' waste sitting on top.

The hydrometallurgical process uses sulphuric acid (gained from the smelting process) as a leachate on the oxidised ores and waste materials. The leaching is commonly undertaken in piles, with the copper rich leachate collected at the bottom. Solvent extraction is then used to remove the copper from the leachate.

### 3. Waste Management

During the ore concentration process waste 'tailings' are produced. These fall to the bottom of the concentration cell where they are removed, dewatered and placed into a tailings pond to allow further drying.

After smelting the waste slag is removed from the furnace and either stored or disposed of on a slag pile. A small amount of slag can be sold on for use in sand blasting, as ballast or for other industrial processes. The sulphur dioxide that is given off in the smelting process is converted into sulphuric acid and used in the hydrometallurgical process.

Waste materials from these sites were often stored or disposed of on-site in open areas or in site landfills.

### 4. Potential Contaminants

The dominant radionuclides in waste rock and tailings are radium-226 and lead-210, but the concentrations vary depending upon the rock type. The more bituminous black rocks have higher concentrations than the white rock and can be above the level for classification as radioactive waste as set out in the Radioactive Substances Act.

Waste slag from smelting may contain slightly increased concentrations of radium-226, potassium-40, lead-210 and polonium-210. The concentrations of these radionuclides could be in excess of the regulatory control limits in the Radioactive Substances Act.

The smoke that is produced in the smelting process contains fine dust particles with elevated concentrations of lead-210 and polonium-210, although these are partially removed by air filters. They can be further purified by passing them through an intensive purification scrubber unit, which produces a waste sludge which contains concentrations of lead-210 and polonium-210, with higher concentrations than other radionuclides such as radium-226.

## 5. Prevalence and Potential Impacts

The majority of the radionuclides 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. Many sites may have slag piles and slurry lagoons, with some sites also having their own landfill areas. The main problem from these waste areas is the production of contaminated dusts. If these become airborne they can increase the possibility of ingestion or inhalation by humans or animals as well as causing the migration of contamination. Slightly soluble contaminants such as radium-226 may also leach from the waste heaps and migrate via groundwater.

Older spoil heaps tend not to generate large amounts of dust as they have a vegetation barrier; this exposure pathway is likely to be limited to times where disturbance of the spoil would increase the generation of dust.

The copper industry produces only low concentrations of radionuclides in its waste products and so will have a very limited radiological impact on the environment. The main environmental pathway is from the leaching and transport of radium-226 from spoil heaps, although the solubility of radium is low. 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.

## 6. Implications for the Part 2A Regime

Concentrations of radioactive contaminants in copper slags are such that they are **unlikely to be capable of** giving rise to an individual effective dose of 3 millisieverts/year above local natural background levels under any reasonable scenario.

## 7. References and further information

Hildegarde, 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. Report ref CARE ECDGXI 96-ET-006. European Communities. 1999.

Indicators for Land Contamination. Environment Agency, Defra, Welsh Assembly Government. 2005.

<http://publications.environment-agency.gov.uk/pdf/SCHO0805BJMD-e-e.pdf>

## DATA SHEET NUMBER A5: ALUMINIUM REFINING

### 1. Background

Aluminium is the most abundant metal in the earth's crust. The most important aluminium bearing mineral being bauxite which can contain up to 55% aluminium, as well as thorium and other naturally occurring radionuclides. The refining of bauxite is a relatively expensive process due to the large amount of electricity needed: twelve to fourteen kilowatts are required per kilogram of aluminium produced. This high energy requirement means that many refining sites are near to power stations, which therefore limits their distribution. Aluminium refining is carried out at only a few sites in the UK.

### 2. Activities

A three step process is usually employed to produce aluminium alloy ingots. First the aluminium is extracted from the bauxite ore using the Bayer process. The Bayer process mixes finely crushed ore with aqueous sodium hydroxide solution forming a slurry. In a digester, the slurry is reacted at high temperature and under steam pressure creating a mixture of dissolved aluminium oxides and residues. The sodium aluminate solution is further purified by the addition of other agents such as starch, and the solution is then sent to a precipitation tank. Electrolytic reduction is then used to produce pure molten aluminium. The aluminium (more than 99% pure) collects at the bottom of the vessel and is siphoned off. The third step involves the processing of the aluminium into alloys or ingots.

### 3. Waste Management

During the digester reactions, the majority of the impurities fall to the bottom of the digester forming a sludge.

Although the refining process produces large quantities of particulate waste, due to its economic value the material particulate emissions are small as the material is collected and recycled to the process. During bauxite refining a solid waste is produced called red mud or sludge. This is the main solid waste and has a high concentration of metals and is caustic in nature.

#### 4. Potential Contaminants

The main radionuclide of concern in the red mud is thorium-232 with typical concentrations ranging from 0.041 to 0.527 Becquerels/gram (Bq/g), values which are well below those requiring control under the Radioactive Substances Act.

#### 5. Prevalence and Potential Impacts

The UK has a 100 year history of aluminium refining, but at only a very few sites. The industry produces only low concentrations of radionuclides in its waste products and so will have a very low radiological impact on the environment. Concentrations of radionuclides in waste are generally below those required for control under the Radioactive Substances Act.

The majority of the radionuclides present in the wastes are alpha emitters with some low energy beta emitters. The main contaminant exposure pathway to human receptors is therefore from internal doses received from the ingestion or inhalation of contaminated materials. The main problem from the waste areas is the production of contaminated dusts. If these become airborne they can increase the possibility of ingestion or inhalation by humans or animals as well as causing the migration of contamination.

The aluminium industry produces only low concentrations of radionuclides in its waste products and so will have a very limited radiological impact on the environment. The main environmental pathway is from the leaching and transport of radium-226 from spoil heaps, although the solubility of radium is low. 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.

#### 6. Implications for the Part 2A Regime

Concentrations of radioactive contaminants in aluminium slags are such that they are **unlikely to be capable of** giving rise to an individual effective dose of 3 millisieverts/year above local natural background levels under any reasonable scenario.



## 7. References and further information

Hildegarde, 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. Report ref CARE ECDGXI 96-ET-006. European Communities. 1999.

Indicators for Land Contamination. Environment Agency, Defra, Welsh Assembly Government. 2005.

<http://publications.environment-agency.gov.uk/pdf/SCHO0805BJMD-e-e.pdf>

## DATA SHEET NUMBER A6: FERROUS METALS REFINING

### 1. Background

The iron and steel industry has a long history in the UK, and is currently dominated by Corus (British Steel). The raw materials (iron ore and coal) are mostly imported (although this was not the case historically), with iron ore originating in South Africa, South America, Australia and Canada. The coal is imported from Australia, Canada and the USA. Limestone, which is also used, is mined in the UK.

### 2. Activities

In the refining of ferrous metals, iron ore is treated by physical and chemical means to produce ferrous products, including various grades of iron, steel and ferrous alloys.

The first activity is the preparation of the ore by sintering or roasting in a furnace with added coal. The sintering process results in the production of an iron rich clinker. This is removed from the furnace and combined with coke and limestone within a blast furnace. This results in molten pig iron forming in the bottom of the furnace. The limestone combines with impurities in the molten metal and forms a slag at the surface, which is regularly removed.

Steel can then be produced from the pig iron. In the UK this is commonly undertaken within a basic oxygen furnace (BOF). In the BOF the molten pig iron has highly pure oxygen injected into it. The oxygen reacts with carbon and silicon, generating heat which in turn oxidises impurities. These impurities are removed in the off gas and the slag is removed from the surface.

### 3. Waste Management

Wastes produced in the sintering process consist of dusts which are removed in the off gas. The gasses are cleaned using electrostatic precipitators. Dust which collects in the precipitators are usually transferred to landfill, although historically in some cases they may have been disposed of locally on-site.

The wet gas cleaning system from the blast furnace and the BOF removes dust in the form of a slurry; this is landfilled after it has been dewatered within large lagoons. Carbon monoxide is also released from the BOF, and after cleaning this can be used as a fuel.

The slag which is produced in the process is cooled and sold, although on many old sites, the slag was stored in open areas for long periods.

#### 4. Potential Contaminants

The sintering process results in the volatilisation of components of the ore including lead-210 and polonium-210. Typical activity concentrations in these dusts can be as high as 11.3 and 99.8 Becquerels/gram (Bq/g) for lead-210 and polonium-210 respectively. These are above the threshold levels set out in the Radioactive Substances Act.

The activity concentration of the dust in the lagoons is approximately 0.4 Bq/g for lead-210 and 0.01Bq/g for polonium-210. These values would not lead to a requirement for controls under the Radioactive Substances Act.

The slag contains low levels of naturally occurring radioactive material (NORM) from the uranium-235, uranium-238 and thorium-232 decay chains.

#### 5. Prevalence and Potential Impacts

The UK has a long history of ferrous metal refining with a large number of historical and current sites located around the UK. There is thought to be approximately 14,000 to 17,000 such sites.

The majority of the radionuclides present in the wastes are alpha emitters with some low energy beta emitters. The main contaminant exposure pathway to human receptors is therefore from internal doses received from the ingestion or inhalation of contaminated materials. Many sites may have slag piles and slurry lagoons, with some sites also having their own landfill areas. The main problem from these waste areas is the production of contaminated dusts. If these become airborne they increase the possibility of ingestion or inhalation by humans or animals as well as

causing migration of contamination. Ferrous slags have been used in road construction and maintenance; and housing construction.

Due to the low solubility of the heavy metal radionuclides, transport to the environment in groundwater is likely to be limited in both extent and concentration.

## 6. Implications for the Part 2A Regime

Concentrations of radioactive contaminants in ferrous slags are such that they are **unlikely to be capable of** giving rise to an individual effective dose of 3 millisieverts/year above local natural background levels.

## 7. References and further information

David Wickers et al. Survey of derelict land in England. HMSO. 1993.

General State of Industry – Coal Mines and Iron Works.

[General State of Industry - Coal-Mines and Iron-Works](#)

Hildegarde, 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. Report ref CARE ECDGXI 96-ET-006. European Communities. 1999.

Indicators for Land Contamination. Environment Agency, Defra, Welsh Assembly Government. 2005.

<http://publications.environment-agency.gov.uk/pdf/SCHO0805BJMD-e-e.pdf>

## DATA SHEET NUMBER A7: LEAD REFINING

### 1. Background

Lead works have been widespread throughout the UK, although there are very few active operations today. Historically, lead was mined in the UK but today the main commercial source of lead comes from overseas or from recycling. The principal ore is Galena (lead sulphide).

### 2. Activities

In the refining of lead, lead ore is treated by physical and chemical means to produce lead at various levels of purity.

The lead ore is prepared by several processes including dry crushing, wet grinding (to produce a slurry), gravity classification and flotation, prior to the main smelting process. Recyclable lead wastes can also be added to the smelting process.

The prepared lead ore is firstly fed into a sintering machine with combinations of other materials such as iron, silica, limestone, coke, soda, ash, pyrite, zinc and sodium hydroxide. In the sintering process, blasts of hot air burn off the sulphur in the lead ore, which is released as sulphur dioxide. After the sintering process the lead material (sinter) consists of approximately 9% weight carbon. This sinter, after the addition of coke, is then reduced within a blast furnace where the carbon acts as a fuel to melt or smelt the lead. The molten lead flows to the bottom of the furnace and divides into four layers according to density:

- 'Speiss' the lightest material (arsenic and antimony);
- 'Matte' copper and other metal sulphides;
- Blast furnace slag (predominated by silicates); and
- Lead bullion, 98% lead by weight.

The lead undergoes a final refining stage using pyrometallurgical methods.

### 3. Waste Management

The 'speiss' and 'matte' can be sold on to copper smelters for copper recovery. The 'dross' produced in the kettles can be fed into a dross furnace, which converts it into 'speiss' and 'matte' which can be fed into copper smelters. The blast furnace slag is typically placed in piles for partial metal recovery by acid leaching.

Many historical sites will have had slag piles and slurry lagoons, with some sites also having their own landfill areas.

### 4. Potential Contaminants

The production of lead only gives rise to radioactively contaminated material in the blast furnace. Slag from the blast furnace contains naturally occurring radioactive material (NORM) dominated by radium-226 with an activity of around 0.26 Becquerels/gram (Bq/g). This is below the activity limit set in the Radioactive Substances Act and does not therefore require formal controls.

### 5. Prevalence and Potential Impacts

The UK has a long history of lead processing with a large number of historical sites located around the UK. The greatest risk is from sites that were operational prior to the regulation of waste disposal. These may be hard to identify due to the lack of documented history.

The majority of the radionuclides present in the wastes are alpha emitters with some low energy beta emitters. The main contaminant exposure pathway to human receptors is therefore from internal doses received from the ingestion or inhalation of contaminated materials. The main problem from the waste areas on these sites is the production of contaminated dusts. If these become airborne they can increase the possibility of ingestion or inhalation by humans or animals as well as causing the migration of contamination as well.

The lead industry produces only low concentrations of radionuclides in its waste products and so will have a very limited radiological impact on the environment.

Furthermore, the relatively low solubility of the heavy metal radionuclides means that transport in groundwater will be limited in both extent and concentration.

## 6. Implications for the Part 2A Regime

Concentrations of radioactive contaminants in lead slags are such that they are **unlikely to be capable of** giving rise an individual effective dose of 3 millisieverts/year above local natural background levels under any reasonable scenario.

## 7. References and further information

David Wickers et al. Survey of derelict land in England. HMSO. 1993.

Hildegarde, 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. Report ref CARE ECDGXI 96-ET-006. European Communities. 1999.

Indicators for Land Contamination. Environment Agency, Defra, Welsh Assembly Government. 2005.

<http://publications.environment-agency.gov.uk/pdf/SCHO0805BJMD-e-e.pdf>

## DATA SHEET NUMBER A8: ZINC REFINING

### 1. Background

The UK has a long history of zinc refining up to the present day. The main ore used for zinc production historically was a sulphide form known as sphalerite, which also contained iron and cadmium as impurities.

### 2. Activities

The ore is prepared by crushing, grinding and is concentrated by flotation. Today this process is more likely to be carried out at the mining site (data sheet A2 covers this aspect).

The basic method of zinc production is the reduction of the ore to a metal. There are two methods for this, the most common being the hydrometallurgical process of electrowinning. (The other method is by pyrometallurgical reduction in a furnace.)

The first step in the hydrometallurgical process is the roasting of the ore concentrate at high temperatures. This converts the zinc sulphide into an impure zinc oxide which vaporises and is removed from the furnace within the gas stream. The zinc oxide is captured in a filter house. The zinc oxide dust is then dissolved in sulphuric acid to form zinc sulphate. Further purification is achieved by the addition of zinc dust, this forces unwanted elements to precipitate so that they can be filtered out. The solution is then fed into an electrolytic cell. An electric current is run from a lead/silver alloy anode and the suspended zinc is deposited on an aluminium cathode. The process takes approximately 24 to 48 hours after which the cathodes are removed and the zinc stripped from the aluminium. The zinc is now 99.99% pure and can be melted and cast.

### 3. Waste Management

The ore concentration method results in waste rock which contains trace amounts of radionuclides. Subsequently, there are two main waste products from the refining process. The first is gaseous sulphur dioxide which is removed from the gas stream and converted into sulphuric acid for resale. There are no radiological implications for



this waste stream. The second is a sludge which can be very slightly radioactive. This is removed from the bottom of the cells after electrolytic refining.

Many former sites had slag piles and slurry lagoons, with some sites also having their own landfill areas for disposal of the above wastes.

#### 4. Potential Contaminants

Sludges generally contain trace amounts of uranium-238 and thorium-232 and decay-chain daughters dominated by radium-226, with concentrations at approximately 0.007 Becquerels/gram (Bq/g). This concentration is insignificant. Waste rock can have equivalent (that is, low significance) concentrations of the same radionuclides.

#### 5. Prevalence and Potential Impacts

The UK has a long history of zinc processing with a large number of historical sites located around the UK. The greatest risk is from sites that were operational prior to the regulation of waste disposal in 1963. These may be hard to identify due to the lack of documented history.

The majority of the radionuclides present in the wastes are alpha emitters with some low energy beta emitters. The main contaminant exposure pathway to human receptors is therefore from internal doses received from the ingestion or inhalation of contaminated materials. The main problem from the waste areas is the production of contaminated dusts. If these become airborne they can increase the possibility of ingestion or inhalation by humans or animals as well as causing the migration of contamination.

The zinc refining industry produces only low concentrations of radionuclides in its waste products and so will have a very limited radiological impact on the environment. Slightly soluble contaminants such as radium-226 may leach from the waste heaps and migrate via groundwater.

## 6. Implications for the Part 2A Regime

Concentrations of radioactive contaminants in zinc processing wastes are such that they are **unlikely to be capable of** giving rise to an individual effective dose of 3 millisieverts/year above local natural background levels under any reasonable scenario.

## 7. References and further information

David Wickers et al. Survey of derelict land in England. HMSO. 1993.

Hildegarde, 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. Report ref CARE ECDGXI 96-ET-006. European Communities. 1999.

Indicators for Land Contamination. Environment Agency, Defra, Welsh Assembly Government. 2005.

<http://publications.environment-agency.gov.uk/pdf/SCHO0805BJMD-e-e.pdf>

## DATA SHEET NUMBER A9: RARE EARTH METAL REFINING

### 1. Background

Rare earths are a group of metals with similar properties, the ores of which are refined to produce lanthanide minerals. The most commonly used rare earth mineral ores (in the form of sand) are monazite and bastnasite. No rare earth mineral ores are mined in the UK or Europe and information of historical refining activities in the UK is extremely sparse. The products from the refinement processes are used in polishes, as catalysts, in X-ray machinery, in cathode ray tubes and as additives in steel and glass. Titanium is also produced from these minerals, the majority of which is used in the iron and steel industry and in aircraft and ship construction.

### 2. Activities

Monazite ore is initially concentrated by gravimetric and electromagnetic sorting. Strong acid and alkaline solutions are then used to precipitate out the lanthanide minerals. Bastnasite ore is concentrated by washing and separating in water and then washing with hydrochloric acid. It is then calcined to produce a crude oxide with a concentration of approximately 90% lanthanum.

The minerals are then treated depending upon their application. Examples of this include heating to high temperatures to produce glass polish and the production of alkaline resistant glass by mixing the rare earth minerals with silica, and subsequent smelting.

Other minerals are contained within the mineral ore, the most commonly utilised being titanium oxide and rutile in the production of titanium. These minerals are crushed and mixed with coal. Titanium tetrachloride gas is obtained by chlorination within furnaces. This gas is collected, condensed and purified. Titanium tetrachloride is then reduced to titanium dioxide.

Furnace slag from the high temperature treatment of rare earth minerals has been found to be mildly contaminated with naturally occurring radioactive material (NORM), these being uranium, thorium and decay chain daughter products. Such slags have been found deposited around processing sites.

### 3. Waste Management

There are two main waste products with the potential to have significant concentrations of radionuclides. The first is waste rock from primary ore processing. The second is a radium bearing by-product precipitated out as a sludge in the refining process.

In the production of titanium, radium precipitates out as radium sulphate which collects within the heat exchangers as a scale.

Many sites had slag piles and slurry lagoons, with some sites also having their own landfill areas.

### 4. Potential Contaminants

The mineral ore (waste rock) has a typical activity concentration of 6-10 Becquerels/gram (Bq/g) of thorium-232, radium-228 and thorium-228; plus approximately 1 Bq/g of uranium-238, radium-226, polonium-210 and lead-210. These concentrations are below the levels which are regulated under the Radioactive Substances Act.

Activity concentrations of the sludge are approximately 3000 Bq/g of radium-228 and 450 Bq/g radium-226. This radium bearing waste has been so high in radium concentration that it has been used in the production of radium products such as radium luminising paint. Typically the concentration of the radium sulphate scale from titanium production is approximately 400 Bq/g of radium-226 which has the potential to cause significant ground contamination. These levels are sufficiently high that, if rare-earth processing was carried out today, then controls under the Radioactive substances Act would be necessary.

### 5. Prevalence and Potential Impacts

The UK has a limited history of rare-earth processing, with a small number of historical sites located around the UK. The greatest risk is from sites that were

operational prior to the regulation of waste disposal in 1963. These may be hard to identify due to the lack of documented history.

The majority of the radionuclides present in the wastes are alpha emitters with some low energy beta emitters. The main contaminant exposure pathway to human receptors is therefore from internal doses received from the ingestion or inhalation of contaminated materials. The main problem from the waste areas on these sites is the production of contaminated dusts. If these become airborne they can increase the possibility of ingestion or inhalation by humans or animals as well as causing the migration of contamination.

The industry can produce radionuclides in their waste products at significant concentrations, and so may have a radiological impact on the environment. Soluble salts of radium-226 may leach from the waste heaps and migrate via groundwater.

## 6. Implications for the Part 2A Regime

Concentrations of radioactive contaminants in rare-earth slags are such that they are **capable of giving rise to** an individual effective dose of 3 millisieverts/year above local natural background levels under some scenarios.

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## [DATA SHEET NUMBER B1: RADIUM LUMINISING WORKS](#)

[\(back to Group B\)](#)

### 1. Background

The activity of applying luminising paint to scientific and electronic equipment so that they could be read in the dark or with low light began in the 1920s. The paint containing radium was mostly manufactured by one firm in the UK, but small quantities were also imported.

Organisations registered under the Luminising Regulations 1947 ranged from producers of radium powders/paint, through distributors to instrument and watchmakers and repairers. In the late 1950s, there were 37 factories registered under the regulations to carry out luminising works. Of these, 14 were owned by the MOD. Twelve of the civilian registered sites have been identified from government archives.

The MOD were the major customer for this type of work and the radium luminising operations of the MOD are also covered under data sheets B3 and B4. Luminising paint was used on equipment such as dials to be used in military vehicles, aircraft and ships, as well as on some sites to mark kerbstones to aid night-time movements. Since the 1960s, less radiotoxic shorter-lived isotopes such as promethium-147 and tritium have been used for this purpose. They have not, to date, been found to have caused significant ground contamination.

Some MOD sites, themselves, contained luminising workshops where instruments were painted and maintained as necessary. Radium luminising paints were used primarily for military purposes between the 1930s and the 1960s; the time of greatest use being during the Second World War.

### 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 the radium luminising compound from radium purified at another site.

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

Prior to painting, removal of old luminising residues from instruments undergoing refurbishment was often required.

### 3. Waste Management

Primary waste products from the luminising workshops included empty paint vials or capillaries, brushes and broken instruments. Where refurbishment activities were undertaken, radium paint scrapings were also generated.

Prior to controls being imposed under the Radioactive Substances Act in 1963, many such wastes would have either been buried directly in a waste disposal area on the site, or they would have been incinerated in an on-site boiler house or incinerator and the residues buried. 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. The resulting ash and cinders from incineration was either used as a granular fill for raising levels, infilling holes or forming paths/hardstandings within the site or buried in waste disposal areas.

Former luminising workshop buildings 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 facilities on MOD sites have already been remediated by MOD and other organisations, but some are likely to remain affected by contamination. This applies in particular to facilities which were never under direct MOD control.

Areas external to the buildings may also have been affected by informal disposal of waste paints and residues, and this may include areas within throwing distance of windows and small burial sites in the soft ground surrounding buildings.

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 of on site. The contaminated materials were either released directly onto the land or buried. There have also been cases where instruments and instrument dials have been found in the ground and in burial areas, indicating that not all sites followed the same waste management procedures.

Prior to the introduction of the Radioactive Substances Act in 1963, in many cases, records of the location of waste disposal areas were not kept, making identification difficult. One of the main sources of information allowing identification will be local knowledge of the practices and operations carried out during disposal activities. 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. However, waste disposal areas may contain waste to a significant depth, which may inhibit the ability to detect radioactive contamination due to the shielding effects of overlying materials. Generally, handheld instruments can only detect radioactive sources such as radium luminised instruments to a depth of about 0.3 metres.

There is little information on the disposal practices of watch and instrument repair workshops or the luminising cottage industry. However, the likelihood is that these wastes were disposed of with normal refuse.

## 5. Prevalence and Potential Impacts

There were only a few large luminising sites in the UK and most of these have already been identified. The degree of contamination at these sites could be significant but this will largely be dependent upon their form and function. A large proportion of the sites, and the hardest to identify, will be the cottage luminising industry. There have been cases in the past of garden sheds and rooms in houses containing old dials being contaminated by large amounts of radium-226.

Radium-226 is a naturally occurring radionuclide and is a daughter product from the decay of uranium. Radium is an alpha emitter also releasing some low energy gamma radiation. As an alpha emitter there is only a low risk of a significant dose being received by direct irradiation. The main exposure pathway to a human receptor is from an indirect dose received from the ingestion of radium contaminated material.



Radium contamination on former luminising works and workshops using luminised instruments would have been contained within a relatively 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 through the movement of finer sediments in water (eg. run off to drains) or through human activity.

## 6. Implications for the Part 2A Regime

Concentrations of radioactive contaminants on radium luminising works, including waste pits, are such that they are **capable of giving rise to** an individual effective dose of 3 millisieverts/year above local natural background levels under some scenarios.

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A C Baker. A review of the potential for radium from luminising activities to migrate in the environment. J. Radiol. Prot. 25 (2005) 127-140.

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In the event that radioactive contamination of MOD land is suspected, the best solution is to formally ask MOD for information. It should be noted that all MOD sites where contamination is suspected would be classed as special sites under the Part 2A regime.

## DATA SHEET NUMBER B2: DEPLETED URANIUM MUNITIONS MANUFACTURE AND TESTING

### 1. Background

The manufacture and testing of munitions has occurred at sites across the UK, by both public and private sector organisations. Certain munitions utilise the physical properties of depleted uranium (DU), and this data sheet addresses the radioactive contamination issues associated with the use of DU.

Uranium occurs naturally as three isotopes: uranium-234, uranium-235 and uranium-238. The civil nuclear industry requires mainly enriched uranium, in which the isotopic concentration of uranium-235 is enriched to approximately 3%. DU is produced as a by-product of this enrichment process, and contains predominantly uranium-238, with only 0.2% uranium-235. This DU is known as 'tails' DU, which is less radioactive than naturally occurring uranium, but it exhibits no difference in chemical behaviour or toxicity.

It should be noted that uranium does not immediately decay to a stable element. Its decay results in other radioactive materials, some of which are of significance on their own such as radium. The chemical processing that results in uranium metal removes the majority of the decay products from the uranium. These decay products need not therefore be taken into account when considering the potential impacts of processed uranium metal, which includes DU.

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, making it suitable for use in armour piercing munitions, as well as radiation shielding, flywheels and counterbalances in aircraft (including helicopters). In addition, it is pyrophoric, which means it catches fire spontaneously and sparks when it impacts or is impacted but only if it is finely divided or heated to temperatures in excess of  $400^\circ\text{C}$ . DU is often used in ammunition as an alloy with 0.75% titanium to further increase its hardness.

Limited, small scale experimental firing of DU weapons began in the 1960s in the UK, and a programme to develop armour penetrators followed in the early 1980s. The majority of publicly-available information about the manufacture and use of DU munitions therefore relates to their use in the last 15 years or so.

DU munitions have historically been made in the UK by the 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. It is known that DU munitions were manufactured until 2002 at the RO Speciality Metals Facility at Featherstone, when their contract was completed.

Firing ranges where DU is known to have been tested all remain under MOD ownership, and existing contamination is being appropriately managed by MOD. Further contamination of the land is unlikely.

## 2. Activities

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 have been regulated under the Radioactive Substances Act (or equivalent arrangements on MOD property). Their location is therefore known.

The munitions manufacture sites which make, or have made ammunition 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. DU is imported mostly from overseas sources. It requires processing into the required penetrators. This involves processes such as casting and machining.

DU rounds have been tested on a very limited number of military testing ranges in the UK. There has also been some test firing of DU rounds into the sea.

## 3. Waste Management

Casting and machining operations give rise to casting slags and turnings respectively. These wastes need to be handled carefully, not least because of their pyrophoric nature. The wastes are generally solid, and usually stored under water or oil. There are no known instances of on-site disposal of DU. Some DU turnings, believed to have originated from non-MOD sites, have been illegally disposed of to open land areas.

#### 4. Potential Contaminants

Tails of DU primarily contains uranium-238. Another source of DU, not used in weapons manufacture, is pile DU, which has been reported to contain traces of radioactive substances other than uranium. These trace substances include americium, neptunium, plutonium and technetium. Pile DU is sourced from reprocessed irradiated uranium from reactors. As both pile and tails DU are processed in common facilities, some cross contamination may have occurred resulting in the presence of contaminants in most DU. However, 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 due to uranium daughter isotopes. All of the uranium isotopes present within DU have relatively long half-lives.

#### 5. Prevalence and Potential Impacts

The main exposure pathway from uranium is by ingestion and inhalation which can result in a high internal dose being received. Uranium exhibits chemical toxicity, and in humans can cause detrimental effects to the kidneys. It may therefore fall under the Part 2A regime as a non-radioactive contaminant.

The environmental fate of DU depends upon the form of its release into the environment (e.g. dusts usually of uranium oxides or fragments of metallic DU), and on environmental factors such as pH, water content of soil etc. DU is commonly alloyed with titanium in munitions to reduce the rate of corrosion.

An experiment 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.

The low solubility of uranium and uranium daughters means that the environmental pathway via groundwaters should not lead to widespread or high levels of contamination. The MOD has commissioned environmental monitoring work at its ranges where DU has been used and has found that this has had a negligible impact on the environment.

## 6. Implications for the Part 2A Regime

Since the practice of DU munitions manufacture entirely post-dates the introduction of the Radioactive Substances Act in 1963, it is **unlikely to be capable of** giving rise to an individual effective dose of 3 millisieverts/year above local natural background levels.

## 7 References and further information

MOD reports detailing these issues are publicly available on the MOD website at [www.mod.uk](http://www.mod.uk) or available on request from MOD.

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The Royal Society Report on Depleted Uranium Part 1. The Royal Society. 2002.

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In the event that radioactive contamination of MOD land is suspected, the best solution is to formally ask MOD for information. It should be noted that all MOD sites where contamination is suspected would be classed as special sites under the Part 2A regime.

## **DATA SHEET NUMBER B3: MOD BURNING GROUNDS**

### 1. Background

Radioactive material is extensively used by MOD as a luminising agent to provide a lightweight light source that operates independently of any external power source. Radium, promethium and tritium have been the main radioactive materials used for this purpose but other isotopes may have been used. Radioactive material is also used in electronic equipment, particularly in valves. After the Second World War, 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. Burning was commonplace at MOD sites as this was the accepted method of disposal of surplus items in the UK, and was industry standard practice. Redundant military aircraft have been burned on aerodromes, particularly in the south of England.

Defence Estates, who manage the land for the MOD, are currently undertaking a programme of Land Quality Assessments on all current defence sites. This programme actively identifies and manages MOD land which is both radioactively and chemically contaminated. It is unlikely that there are any unknown sites.

### 2. Activities

The burning of waste material on burning grounds was an established practice on bases, and was not limited to instruments containing radioactive materials. The principal purpose was to reduce the volume of the wastes. 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 and lacking in vegetation. On some bases, the burning areas have been resurfaced to allow other uses.

### 3. Waste Management

Wastes arose from the burning of vehicles, aircraft and ships components. It was buried in-situ at, or local to, the burning ground.

#### 4. Potential Contaminants

The principal contaminant of concern is radium-226, contained in burned residues for military equipment, mainly aircraft, which were equipped with luminised instruments. Contamination may also have arisen from the use of other luminising radionuclides, thorium, and miscellaneous beta emitters.

#### 5. Prevalence and Potential Impacts

Historical radioactive contamination has arisen from standard industry practices that reflected the lack of understanding of the effects of radioactivity at the time.

Where there is a lack of documentary evidence on a specific site, the identification of areas which may be affected by radioactive contamination can only be based in part upon local knowledge of site activities (for example, from personnel who have been based at a site) and experience of similar sites. However, the only reliable method of determining the presence of radioactivity is through appropriate monitoring of the site.

Local contamination by radium could have dose implications for human receptors via the ingestion or inhalation of wind blown dusts.

Radium contamination on burning grounds would have been contained within a relatively 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 have occurred through the movement of finer sediments in water (eg. run off to drains) or through human activity.

Other radiological contaminants are unlikely to be significant in terms of concentration or radiotoxicity. Although tritium is highly mobile, environmental concentrations are likely to be low.

## 6. Implications for the Part 2A Regime

Radioactive contaminants from former MOD burning grounds are such that they are **capable of giving rise to** an individual effective dose of 3 millisieverts/year above local natural background levels, but only in circumstances where extensive burning of luminised equipment took place.

## 7. References and further information

In the event that radioactive contamination of MOD land is suspected, the best solution is to formally ask MOD for information. It should be noted that all MOD sites where contamination is suspected would be classed as special sites under the Part 2A regime.



## DATA SHEET NUMBER B4: MOD MAINTENANCE FACILITIES

### 1. Background

MOD workshops handled a range of radioactive materials. The principal potential problem is associated with radium luminising operations, which are described in a separate data sheet (B1). This data sheet covers other possible contamination issues.

Whilst the requirements of the Radioactive Substances Act do not apply to the Ministry of Defence, in normal circumstances they voluntarily apply the requirements of the Act to their processes.

Defence Estates who manage the land for the MOD are currently undertaking a programme of Land Quality Assessments on all defence sites. This programme actively identifies and manages MOD land which is both radioactively and chemically contaminated. It is unlikely that there are any unknown sites under MOD control. However, but former sites (released from MOD control some decades ago) may still pose as problem.

### 2. Activities

Most MOD sites contained maintenance and workshop areas, although not all of these would have 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). The RAF and Navy used similar bodies to maintain and refurbish instrumentation at their bases.

In addition to radium luminising, workshops are known to have used:

- Tritium in night sights;
- Caesium-137 and other radionuclides in electronic valves;
- Various radionuclides in calibration sources; and
- Thorium in optical instruments.

In addition, unsealed sources have been used as tracers for specific applications, and thorium has arisen in welding residues.

Small quantities of radioactive materials are still used today on some MOD sites under strict controls. This includes betalights, electronic valves and sealed radioactive sources for instrument calibration and testing. The use of such sources are recorded by the MOD, with records kept by Dstl (Defence Science and Technology Laboratory) Environmental Sciences Department.

### 3. Waste Management

Historical radioactive contamination has arisen from past practices that reflected the lack of understanding of the effects of radioactivity at that time. Wastes arose either from within luminising workshops, which were present on some establishments, or from the maintenance or dismantling of vehicles, aircraft and ships.

The ad hoc burial of waste components at localised disposal points around sites was generally confined to soft areas around workshops and maintenance areas. Waste disposal areas may contain waste to a significant depth, which may inhibit the ability to detect radioactive contamination due to the shielding effects of overlying materials. Generally, handheld instruments can only detect radioactive sources such as radium luminised instruments to a depth of about 0.3 metres.

In the case of incineration, the resulting ash and cinders was either used as a granular fill for raising levels, infilling holes or forming paths/hardstandings within the site or buried in waste disposal areas. There have also been cases where instruments and instrument dials have been found in the ground and in burial areas, indicating that not all sites followed the same waste management procedures.

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 involved in luminising activities have been demolished and the land levelled; and
- Areas around the incinerators and boiler houses, where combustion residues were spread.

#### 4. Potential Contaminants

In addition to radium-226, the main radionuclide of concern, contamination may have arisen from the use of other luminising radionuclides such as thorium and miscellaneous beta emitters. Less radiotoxic and shorter-lived isotopes, specifically promethium-147 and tritium, have been used in luminising operations in recent years. Promethium-147 is a beta emitter which also emits gamma radiation. It does not persist for long periods in the environment with a half-life of 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 contamination on MOD sites.

#### 5. Prevalence and Potential Impacts

Land that has been used for defence maintenance purposes is found throughout the UK. Only a small proportion of these sites will have used or disposed of radioactive materials, and, of these, even fewer will have handled large quantities of them.

Where there is a lack of documentary evidence on a specific site, the identification of areas which may be affected by radioactive contamination can only be based upon local knowledge of site activities (for example, from personnel who have been based at a site) and experience of similar sites. This is particularly a problem with land, which was divested from MOD ownership shortly after the Second World War, or where the land ownership was transferred between sections of the MOD. There is

often little evidence of the existence and use of a site within public records. Sites are often 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.

Radium-226 is a naturally occurring radionuclide and is a daughter product from the decay of uranium. Radium is an alpha emitter also releasing some low energy gamma radiation. As an alpha emitter there is only a low risk of a significant dose being received by direct irradiation. The main exposure pathway to a human receptor is from an indirect dose received from the ingestion of radium contaminated material.

Radium contamination on former luminising works and workshops using luminised instruments would have been contained within a relatively 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 through the movement of finer sediments in water (eg. run off to drains) or through human activity.

## 6. Implications for the Part 2A Regime

Radioactive contaminants (specifically radium) from former MOD maintenance facilities are **capable of giving rise to** an individual effective dose of 3 millisieverts/year above local natural background levels, but this is only likely to occur in situations where radium luminising is known to have taken place (see data sheets B1 and B3).

## 7. References and further information

MOD reports detailing these issues are publicly available on the MOD website at [www.mod.uk](http://www.mod.uk) or available on request from MOD.

In the event that radioactive contamination of MOD land is suspected, the best solution is to formally ask MOD for information. It should be noted that all MOD sites where contamination is suspected would be classed as special sites under the Part 2A regime.

## DATA SHEET NUMBER C1: OIL AND NATURAL GAS FACILITIES

(back to Group C)

### 1. Background

The oil and gas support industry is the land-based infrastructure set up to support the exploration and extraction of oil and gas both onshore and offshore. (A separate data sheet C3 covers historical land-based gas production).

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), comprising mainly uranium, thorium and decay chain daughters, with radium species being the principal radionuclides of concern. 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.

The UK petroleum industry began with the drilling of the first well in 1859. Oil shales occurring mainly in England and Scotland were used for oil production. The two key areas exploited were the Kimmeridge shales of southern England (which were worked from the mid 1800s), and Mid and West Lothian in Scotland (where activity peaked in the 1870s). The last UK oil shale works closed in 1964. These early industries were in operation prior to the Radioactive Substances Act coming into force in 1963, and could therefore have resulted in historical contamination. Recent oil and gas production has centred on activities in the North Sea with 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.

### 2. Activities

#### General

At oil and gas extraction sites, water is pumped into the well to maintain a high pressure which forces material to the surface. This water dissolves radium contained

within the source rock, and when the 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 may increase the rate of precipitation due to the increased sulphate content.

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

### Offshore

NORM associated with oil and gas production includes contaminated water, scales and sludges. Scales can 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 (that is, scales which require mechanical means for removal) can be deposited at well heads and at the production manifolds, with softer scales formed further downstream, e.g. in production pipes and vessels. Lead scale, which is observed in gas or oil fields with high gas yields, comprises a thin coating, rather than a hard scale. Sludges are deposited in storage tanks, separators, dehydration vessels etc. It is the sludges which contain the majority of the radioactivity associated with NORM in the oil and gas industries.

### Onshore

Decontamination facilities exist onshore 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 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 is available. This does not preclude the possible historical existence of others.

The items of equipment sent for decontamination are predominantly pipes, but can 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 are wrapped 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.

### 3. Waste Management

The waste materials generated by the de-scaling operations comprise 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 Drigg Disposal Facility in Cumbria. 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 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 the sea.

With respect to the quantities of scale generated, one UK de-scaling site produced approximately 19,000 kg and 26,000 kg during 1993 and 1994, with the total activity estimated as approximately 5 Gigabecquerels/kg (GBq/kg) 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 is available 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 Becquerels/g respectively. These concentrations are such that controls under the Radioactive Substances Act are required.

### 4. 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 gas terminals where the

radionuclide being mobilised from the geological formation is almost 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 scales and sludges are highly variable due to variations in the nature of the reservoirs and other environmental conditions.

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

Uranium-238 and thorium-232 can be present in abstracted 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, as formation water preferentially dissolves calcium, strontium and radium rather than uranium and thorium.

Information on the decommissioning of sites associated with the UK oil and gas industries is sparse. Data relating to a site in Croatia details that a dose rate of 70 millisieverts/hr was recorded at the surface of pipelines, which in certain circumstances could result in a significant dose being received.

## 5. Prevalence and Potential Impacts

There are few land based sites that have handled NORM contaminated scales and sludges in the UK. These should have been identified as they will have been under the control of the Radioactive Substances Act.

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 dusts contaminated with NORM.



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

## 6. Implications for the Part 2A Regime

Currently, descaling operations are in well managed large throughput operations at a limited number of sites. Contamination levels, and the degree of controls, are such that they are **unlikely to be capable of** giving rise to an individual effective dose of 3 millisieverts/year above local natural background levels under any reasonable scenario. Historically, some enhanced concentrations of NORM may have occurred as a consequence of descaling, but the much smaller scale of these operations are such that they would also be **unlikely to be capable of** giving rise to an individual effective dose of 3 millisieverts/year above local natural background levels under any reasonable scenario.

## 7. References and further information

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## DATA SHEET NUMBER C2: COAL-FIRED POWER STATIONS

### 1. Background

Most early power stations built in the UK were coal fired, the exceptions being a small number of hydro-electric plants. Many small stations were 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 fired power stations were often located near coal mining areas. In 1926, there were 438 coal fired power stations. The number of individual stations has declined over time to 22 stations in 2004. This has resulted from centralisation, a trend towards bigger, more efficient stations, and the advent of alternative sources of fuel such as gas, oil and nuclear power. In 1995, 26 of the 86 power stations in the UK were coal fired.

All coal contains low concentrations of naturally occurring radioactive material (NORM), these being uranium and thorium species, and decay chain daughters of these species. The combustion of coal, in coal-fired power stations releases volatile radionuclides and concentrates non-volatile radionuclides in the resultant ash.

### 2. Activities

At coal-fired power stations, the coal is stored in stockpiles directly in contact with the ground. The coal is usually pulverised and blown into the furnace. A typical coal-fired power station includes a number of units in which pulverised coal is burnt at temperatures between 1100 and 1700 °C. Two types of ash are produced from coal combustion:

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

The total volume of ash produced, and the proportion of the two types of ash varies with the type of coal being burnt. Radionuclides are not combusted since they are part of the mineral constituent of the coal. They therefore remain in the ash.

At high temperatures, volatilisation of some compounds containing radionuclides does occur. 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, and 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 the type of coal burnt, whether the coal is pulverised before combustion, the type of furnace used and the operating temperature.

In addition to ash, there is evidence that radionuclides 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 lead-210 activity concentrations in excess of 100 Becquerels/gram (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.

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.

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 radionuclides in volatile compounds released during combustion may condense on the chimney interior. Some materials with enhanced radioactivity may be left on site after demolition.

### 3. Waste Management

Small quantities of the ash generated by coal-fired power stations escape to the 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 which was landfilled and 51% sold on, predominantly for use in construction materials.

Ash may accumulate at the power station pending final disposal, or may be disposed of on-site, e.g. in above ground landscaped features which are covered with topsoil and vegetation. In the UK, the largest ash pile found at a power station 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. 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 the atmosphere. In addition to its use as construction fill material in roads and embankments, fly ash can be used in construction materials such as cement, bricks and blocks. The fly ash can also be sintered and used as an aggregate. Bottom ash is usually used as aggregate for concrete or in the construction of roads.

#### 4. Potential Contaminants

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. The activity concentration of coal varies by 2 – 3 orders of magnitude depending upon its type and origin. 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/g. This is a negligible quantity, hardly measurable against environmental concentrations of NORM.

#### 5. Prevalence and Potential Impacts

There have been over four hundred historical coal-fired power stations and with coal combustion taking place at numerous other industrial sites, there is the potential for coal ash to be widely distributed throughout the UK.

The radionuclides present in coal ash are in very low activity concentrations and therefore pose little risk to human health or the environment. They are alpha emitters and the main exposure pathway is via inhalation or ingestion.

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 were insignificant.

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

Work by the National Radiological Protection Board, published in 2001 indicates that PFA has a low radiological risk, below levels which require regulation under either the Radioactive Substances Act 1993 or the Ionising Radiations Regulations 1999.

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 at 0.007 Bq/g for radium-226 is within the range for natural gypsum estimated as 0.004-0.030 Bq/g.

The main pathway for dose uptake is therefore by ingestion or inhalation of fly-blown ash.

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

Due to the low solubilities of the principal contaminants, transport into the environment by groundwater is likely to be limited.

## 6. Implications for the Part 2A Regime

Concentrations of radioactive contaminants in by-product wastes from the coal-fired power industry are such that they are **unlikely to be capable of** giving rise to an individual effective dose of 3 millisieverts/year above local natural background levels under any reasonable scenario.

## 7. References and further information

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## DATA SHEET NUMBER C3: GAS INDUSTRY

### 1. Background

Historically, town gas was produced using a catalysed industrial process. Only a small number of gas production sites in the UK utilised radioactive materials. These were sites which adopted a high pressure reforming process for the production of gas. The radioactive material used was uranium oxide, which promotes the catalyst in the process. It should be noted, however, that uranium oxide was only used on some sites, with many sites using nickel oxide as the promoter. These processes have now been entirely superseded by the use of natural gas, for which a separate data sheet has been prepared at C1.

### 2. Activities

Town gas production in the UK involved the continuous reaction of various hydrocarbon feedstocks such as liquid petroleum gas, light distillate spirit and naphtha, with steam in the presence of a catalyst. On a small number of sites, the method of gas production involved continuous vapour phase reactions conducted at high pressure (with a catalyst). This produced a low calorific value gas, which was enriched prior to distribution.

The catalysts were generally ceramic, promoted by either nickel or uranium oxide, although other catalysts were also used to convert carbon monoxide into carbon dioxide and to hydrogenate sulphur compounds.

### 3. Waste Management

Unlike other methods of gas production, the high pressure reforming process was relatively clean and did not produce the tar or effluents associated with other processes. In general, the production of town gas preceded controls imposed under the Radioactive Substances Act which came into force in 1963. No information has been found on the disposal method used for the uranium oxide (or other catalysts used), but it is likely that catalysts were disposed of with general scrap. In-situ disposal to an on-site landfill is a possibility.

#### 4. Potential Contaminants

The only known radioactive material utilised on gas work sites is uranium in the form of uranium oxide. Not enough information is available to suggest possible activity concentrations, but very large quantities are not likely.

#### 5. Prevalence and Potential Impacts

Contamination of gas work sites with uranium oxide is likely to be limited as this technique was not widely adopted around the UK. Experimental gas works are most likely to have utilised such materials. The majority of these sites will have been identified due to the ongoing management of former and current gas work sites by SecondSite Properties. Due to the lack of information available on the form of radioactive contaminants no assessment on the potential impacts can be made. However, the probability of a former gas works site having areas of contamination due to buried catalyst material is extremely low. Additionally, even if such contamination was present, the dose implications would be negligible. Uranium and uranium oxides are relatively insoluble, such that transport by groundwaters would be limited both in extent and radioactive concentration.

#### 6. Implications for the Part 2A Regime

Concentrations of radioactive contaminants in by-product wastes from the historical gas industry are such that they are **unlikely to be capable of** giving rise to an individual effective dose of 3 millisieverts/year above local natural background levels under any reasonable scenario.



## 7. References and further information

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## DATA SHEET NUMBER D1: LANDFILL SITES

### (back to Group D)

#### 1. Background

Certain radioactive wastes are permitted to be deposited at landfills. Materials classified as Very Low Level Waste (VLLW) and exempt waste (as defined by various exemption orders under the Radioactive Substances Act) may be accepted at certain landfills. This practice has been permitted only following a rigorous radiological impact assessment which has demonstrated that such disposals do not lead to significant radiation doses to human beings.

It is likely 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 historically and in existence prior to the introduction of the Radioactive Substances Act in 1963 (as identified in other data sheets) are those likely to have the greatest potential for unrecorded radioactive contamination.

#### 2. Activities

In landfilling activities, commercial and domestic wastes are deposited in trenches or pits in a designated area and compacted. Prior to closure, some landfills may have been covered with a clay cap and landscaped. Modern landfills have a higher degree of engineering, usually being lined at the base, fitted with facilities for gas and water channelling, and operated to well-defined standards of waste depth and degree of compaction.

Historically, materials were not segregated before disposal to landfill, and thus any pre-Control of Pollution Act 1974 (CoPA) sites have the potential to contain radioactive materials. The use of radioactive materials, and the consequent possibility of disposal to landfill, was historically more widespread than at present. For example, a cottage luminising industry existed where home-workers used luminous paints to paint instruments, watches and clocks.

Wastes from these activities are likely to have arisen from the early 1900s onwards and will have been disposed of along with domestic refuse. An example of historic waste disposal practice was 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'.

Following the introduction of the CoPA, radioactive materials could have been deposited in landfills inadvertently e.g. commonplace articles such as smoke detectors and certain luminescent materials which are not commonly thought of as radioactive by members of the public.

Certain landfill sites have been able to accept radioactive materials that are either exempt from the Radioactive Substances Act or that have been given Special Precautions Burial approval, this being the disposal of Low Level Radioactive Waste (LLW) to a landfill site after an authorisation has been issued by the environmental regulators.

### 3. Waste Management

Landfill gas and leachate are wastes generated by the landfilling process which are continually released to the environment. 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 disperse to groundwater and thus for radionuclides to migrate off site.

Volatile radionuclides may be associated with landfill gas. Landfill gas is commonly collected and burned or released at certain points on modern landfills. However, the migration of landfill gas either through a capping layer, or laterally through the ground is more common in older landfill sites.

### 4. Potential Contaminants

There is the potential for a large range of radioactive contaminants to be present at landfill sites. When evaluating the potential for individual radionuclides to be present, the age of the wastes is key since radionuclides with relatively short half-lives may have decayed to insignificant levels, whilst those with long half-lives will persist. Landfill disposal records since the introduction of CoPA in 1974 may contain details of radioactive material that has been disposed of as exempt waste or under an authorisation, but such records are not always readily accessible.

Of the potential contaminants possible, it should be noted that in general metals are relatively non-mobile, while tritium can be highly mobile, thus presenting the greatest

potential for land contamination. Tritium has been incorporated into lighting devices (gaseous tritium light devices), many of which have been legally disposed of to landfill sites. Illegal disposals of larger tritium sources is also probable.

## 5. Prevalence and Potential Impacts

Landfill sites are prevalent throughout the UK (tens of thousands of operating and closed sites are known to exist), but potentially serious impacts are believed to be few except in some well defined circumstances e.g. old landfills which have historically received wastes from industries which are known to have generated radioactive wastes prior to formal regulatory controls.

Wastes are compacted and buried at landfill sites, thus minimising the possibility of uptake by inhalation or ingestion of wind-borne dusts. Old landfills are generally covered with vegetation, further restricting the spread of dusts. The main pathway to the environment, and hence to humans, is therefore via leaching into groundwater.

Although any one of a number of radionuclides could be present in a landfill site, highly mobile tritium species could present a problem, and tritium has been detected in low concentrations in groundwater near to landfill sites. Carbon-14 and caesium-137 have also been detected at very low levels in groundwater close to landfill sites.

Low levels of tritium have been detected in grass samples from the vegetation cover of closed landfills. Calculations have shown these levels to be of negligible radiological significance.

## 6. Implications for the Part 2A Regime

Concentrations of radioactive contaminants in landfills are such that they are **capable of giving rise to** an individual effective dose of 3 millisieverts/year above local natural background levels. However, this is only likely to occur on landfills which pre-date formal arrangements for LLW disposal under the Radioactive Substances Act in 1963 and which are in close proximity to industrial sites which have generated radioactive wastes.

## 7. References and further information

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## DATA SHEET NUMBER D2: SEWAGE WORKS AND LAND RECEIVING TREATED SEWAGE

### 1. Background

Sewage farms originated during the second half of the nineteenth 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.

The increase in volumes of sewage brought about the development of sewage treatment works which minimised 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 their concentrations in the sewage treatment products.

Before the Radioactive Substances Act was introduced in 1963, it is possible that effluents containing radionuclides were discharged to sewers by the various industries discussed in other data sheets. A single sewage treatment works may therefore have received radioactive discharges from a number of differing facilities.

Today, radionuclides are discharged into the sewage system by various facilities such as hospitals, universities, research institutes and industry under appropriate authorisations issued by the environmental regulators.

### 2. Activities

Sewage treatment can comprise up to 4 stages:

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

The fate of radionuclides present in 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 radionuclides being present in the sludge. 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.

### 3. Waste Management

Sewage is commonly spread directly on the land at sewage farms.

The liquid effluent is commonly disposed of to surface watercourses or to the sea, and hence any radionuclides which remain in the liquid phase after partitioning will be released into these receiving waters.

Disposal practices for sewage sludge have changed over time, most notably when sea disposal (which was commonly used in the east of the UK) ceased 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 the sea, 8% was landfilled and 7% was incinerated.

The application of sewage sludge to agricultural land is the most common disposal option and occurs via spreading or direct injection during ploughing. This occurs after appropriate treatment of the sludge has taken place to reduce the risks posed by pathogens. Other associated uses of the sludge include its application to derelict land to aid restoration and use on 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. Co-disposal ceased with the adoption of the Landfill Directive (2000) into UK legislation.

Some sewage sludges are incinerated in commercial incinerators.

#### 4. Potential Contaminants

There is the potential for a wide range of radionuclides to be present at sewage works and in the effluent and sewage sludge produced. Researching 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 data sheets) 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 have common characteristics. They are usually chosen for their ease of measurement, low radiotoxicity and relatively short half-life.

As mentioned above, radionuclides discharged to sewers will vary from place to place, depending upon the nature of the industries feeding any particular sewer. A study of two large sewage works (in Leeds and London) identified eight key radionuclides: tritium; carbon-14; phosphorus-32; sulphur-35; chromium-51; technetium-99m; iodine-125 and iodine-131.

In addition, authorisations for discharges upstream of the works existed for: gallium-67; indium-111; thallium-201; rubidium-83; rubidium-84; strontium-89; yttrium-90; iodine-123 and americium-241.

Many of these have short half-lives (of only a few days) and will decay rapidly. The study concluded that the concentrations of most of the radionuclides analysed 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 when sludges were incinerated.

#### 5. Prevalence and Potential Impacts

Sewage treatment works are widespread, and most, if not all, will receive some radioactive waste for treatment. However, discharges to sewers are predominantly of low half-life radionuclides, which will have been authorised by the environmental regulators. Such authorisations will only have been granted following a satisfactory



radiological impact assessment which has demonstrated that the impacts of the resulting solid waste disposals to land are low. The main pathway for human uptake of such radionuclides is via ingestion of foodstuffs grown on land on which sludge has been deposited.

## 6. Implications for the Part 2A Regime

Concentrations of radioactive contaminants in solid wastes disposed of as a result of sewage treatment operations are such that they are **unlikely to be capable of** giving rise to an individual effective dose of 3 millisieverts/year above local natural background levels under any reasonable scenario.

## 7. References and further information

Department of the Environment. Industry Profile: Sewage Works and Sewage Farms. 1995.

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## DATA SHEET NUMBER D3: INCINERATORS

### 1. Background

Incinerators have been used for the disposal of domestic or municipal wastes since 1876, but their use as a waste disposal method has increased (and continues to increase) in recent times. Incinerators are used to reduce volumes of waste by combustion. Large incinerators are used for the destruction of domestic and commercial wastes. They are also commonly associated with hospitals, universities and research institutes, since they have the advantage of destroying biological matter (such as pathogens) present in the wastes. Such facilities also have the potential for the intake of radioactive material in a waste stream and the generation of combustion waste containing radionuclides.

### 2. Activities

There are various designs of incinerator, which operate at different temperatures and on different scales. Small incinerators are often associated with hospitals, while large commercial incinerators take wastes from a wide catchment area. The waste is burned in fixed-hearth (older) or rotating kiln (modern) incinerators, with off-gases treated in scrubbers. Increasingly, energy recovery is a feature of large commercial incinerators ('waste to energy plant').

An increasingly common practice is the incineration of sewage sludge. This is because of the ban on dumping sewage sludge at sea, which was common practice in the UK until 1998. As described in the data sheet on sewage works (D2), radionuclides may be present in sewage sludge because of authorised discharges of radioactive effluents to the sewers.

### 3. Waste Management

Incinerators reduce, but do not eliminate, waste volumes. After incineration, ash containing the non-combustible components of the waste remains. Commonly, this will include radionuclides associated with heavy metals. The ash is normally landfilled, but has historically been used for construction e.g. for road sub-bases.

During combustion, off gases are produced which will contain any volatile radionuclides. Any radionuclides associated with small light ash particles may also escape with the off gases. Many modern incinerators have plant such as scrubbers or electrostatic precipitators which capture either gaseous or particulate radionuclides.

#### 4. Potential Contaminants

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. Any radionuclide commonly used in both the nuclear and non-nuclear sectors could potentially arise in one of the incinerator waste streams. However, it is unlikely that alpha emitters will be present, except at one incinerator specifically authorised to receive alpha wastes. Moreover, there will be a predominance of short half-life wastes, principally arising from medical applications.

#### 5. Prevalence and Potential Impacts

Incinerators which can and do take radioactive wastes are numerous, and located throughout the UK. Of the three possible waste streams:

- Residual ash is sent to landfill. It is not disposed of on-site. There is therefore no environmental or human health impact local to the incinerator.
- Scrubber liquors are discharged to water courses or sewers under controlled conditions; that is, within limits on radionuclide discharges established under authorisations granted under the Radioactive Substances Act such that they cannot cause a contamination problem to human or environmental receptors.
- Gaseous discharges comprising mainly short half-life beta emitters or carbon-14/tritium are controlled and limited, such that the quantities discharged are highly unlikely, after depositing on land, to lead to a problem of radioactive contamination.

The main pathway to humans and the environment is via air discharges which then deposit on land and are taken up in the food chain.

## 6. Implications for the Part 2A Regime

Discharges of radioactive contaminants from incineration are such that they are **unlikely to be capable of** giving rise to an individual effective dose of 3 millisieverts/year above natural background levels under any reasonable scenario.

## 7. References and further information

Environment Agency and Scottish Environment Protection Agency public registers contain files on every operating incinerator which burns radioactive waste. These files contain information on prospective doses and historical discharges.

## DATA SHEET NUMBER D4: SCRAP RECYCLING

### 1. Background

Scrap metal yards are widespread, and can vary in size from small businesses to large ship breaking sites. Radioactive contamination may be present in the materials being processed as scrap, but may also escape into the ground below.

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

### 2. Activities

Scrap recycling activities include receipt, sorting and onward dispatch of valuable recovered metals. Some cleaning processes also take place, typically degreasing, but also slag and scale removal.

Scrap yards have been found to contain a range of contaminated materials. Heavy radioactive industrial sources (such as industrial gamma-ray sources and thickness gauges) have been found in scrap and in some cases radioactive sources have been incorporated into products made from recycled metal.

Naturally occurring radioactive material (NORM), principally uranium, thorium species and decay chain daughters, has been found on tubing from oil and gas exploration; and in pipes, valves and heat exchangers from the chemical and fertiliser industries.

### 3. Waste Management

Wastes comprise small sealed sources, surface contaminated items (such as pipework with internal NORM scale) and slags/drosses.

Many scrap yards now have radiation monitoring devices either at the entrance to the yard, or on the cranes used to move material. 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 of contamination at the scrap yard.

Waste radioactive material is often collected in drums or in heaps on open ground in the case of scales or loose contamination. It is disposed of to landfill in the case of minor contamination. For sealed sources, a specialist waste contractor is required to take wastes for long-term storage.

#### 4. Potential Contaminants

For sealed sources, the most likely contaminants are to be found in large industrial gamma-radiography instruments with caesium-137 in metal form. NORM scales can contain anything in the uranium and thorium decay chains.

#### 5. Prevalence and Potential Impacts

Although there are many (approximately 3000 to 4500) breaker and scrap yards in the UK, only a small number are likely to have received radioactive materials.

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 for workers due to direct radiation from a large sealed source cannot be discounted.

Incidences in the UK have occurred where high activity sources have been found within scrap metal, but there is a very low potential for such high activity sources to have been dispersed causing land contamination. There are therefore unlikely to be any sites in the UK with the potential for ground contamination which would result in a significant dose being received by a member of the public.

## 6. Implications for the Part 2A Regime

Concentrations of radioactive contaminants in wastes from the scrap recycling industry are such that they are **unlikely to be capable of** giving rise to an individual effective dose of 3 millisieverts/year above local natural background levels under any reasonable scenario.

## 7. References and further information

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Environment Agency, Defra, Welsh Assembly Government. Indicators for Land Contamination. 2005.

<http://publications.environment-agency.gov.uk/pdf/SCHO0805BJMD-e-e.pdf>

## DATA SHEET NUMBER E1: PHOSPHATE INDUSTRY

### (back to Group E)

#### 1. Background

Phosphate compounds are produced from processing phosphate rich rocks (tricalcium phosphate). Such rocks also contain small proportions of naturally occurring radioactive material (NORM), principally uranium, thorium and decay chain daughters. Phosphate ores processed in the UK originate from Africa, Israel and the USA.

Phosphates have a number of applications, principally in detergents and fertilizers.

#### 2. Activities

Historically, phosphate rock was dried, crushed, and then fed into a reactor along with sulphuric acid. Phosphoric acid was produced by the reaction of sulphuric acid with the rock. The reaction combined calcium from the phosphate rock with sulphate, forming calcium sulphate, commonly referred to as gypsum or phosphogypsum.

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

#### 3. Waste Management

After washing, the slurried gypsum, which contains the majority of the NORM from the phosphate rock, is pumped into a gypsum pond for storage and drying prior to disposal. On some sites, the gypsum is disposed of as a dilute slurry to sea-pipelines. Historically, particularly at the smaller sites, the solid product may have been held in waste heaps on site, or even disposed of to an on-site landfill.

#### 4. Potential Contaminants



Phosphogypsum contains activity concentrations of approximately 0.7 Becquerels/gram (Bq/g) radium-226, 0.01 Bq/g thorium-232, 0.5 Bq/g uranium-238, 1.3 Bq/g lead-210 and 0.9 Bq/g polonium-210, but this is dependent upon the concentration found in the mined phosphate-rich rocks. These concentrations, although greater than natural background, are below those requiring control under the Radioactive Substances Act.

## 5. Prevalence and Potential Impacts

Five sites in the UK have been identified where this activity has taken place. The greatest risk of waste problems is from sites that were operational prior to the regulation of waste disposal. These waste problems may be hard to assess due to the lack of documented history.

The majority of the radionuclides present in the wastes are alpha emitters. The main contaminant exposure pathway to human receptors is therefore from internal doses received from the ingestion or inhalation of contaminated materials.

The industry produces only low concentrations of radionuclides in its waste products and so will have a very limited radiological impact on the environment. Slightly soluble contaminants such as radium-226 may leach from the waste heaps and migrate via groundwater, although environmental concentrations are likely to be extremely low.

## 6. Implications for the Part 2A Regime

Concentrations of radioactive contaminants in by-product wastes from the phosphate industry are such that they are **unlikely to be capable of** giving rise to an individual effective dose of 3 millisieverts/year above local natural background levels under any reasonable scenario.

## 7. References and further information

Environment Agency. Historic and current UK use of radioactive materials. R & D Technical report No P307. 1999.

Department of the Environment. Industry Profile: Chemical works, fertiliser manufacturing works. 1996.

## DATA SHEET NUMBER E2: GAS MANTLE PRODUCTION

### 1. Background

Gas mantles were widely used for lighting purposes in domestic dwellings, schools, and for street lamps by 1895. They were originally comprised of a lighting device incorporating thorium. Gas mantle manufacture peaked in the first half of the twentieth century, at a time prior to the strict regulation of waste disposal activities under the Radioactive Substances Act. After this time alternative sources of light became more widely available but gas mantles continued to be used for camping and caravanning. They continue to be used today for camping lights, but are now manufactured without using radioactive materials.

### 2. Activities

The mantles were made by the impregnation of cloth with nitrate of thorium and other metals. The fabric was made by knitting cotton or silk into a fine cloth, and then saturating it in a 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. When the mantle was heated in a gas flame, the cloth was burnt away and the nitrates decomposed to leave a thin and delicate gauze-like structure which consisted mainly of thorium dioxide. Thorium dioxide has a very high melting point (>3000°C) which made it suitable for use in gas mantles; however the mantle structure was very delicate and required strengthening by collodion to enable transportation. The collodion burned away during the first use of the gas mantle.

It is reported that there were five companies engaged in the manufacture of gas mantles during the 1950s. However, the existence of earlier sites which had closed by that time cannot be discounted.

### 3. Waste Management

It was common practice in this era to dispose of thorium contaminated waste material in the most convenient manner, which was often by deposition at the manufacturing site. Some landfills were operating during this time so it is possible that wastes from gas mantle manufacture were deposited there too. It is known that some areas of the Thorium Ltd site in East London were used for waste disposal.

Since the introduction of the uranium and thorium exemption order (1962) under the Radioactive Substances Act, gas mantles themselves have been exempt from special regulations governing their disposal, which means that they could have been included with domestic and commercial wastes destined for landfill.

#### 4. Potential Contaminants

Waste products from the manufacture of gas mantles have the potential to be contaminated with thorium and its decay products. Individual gas mantles in common usage by the MOD were estimated to contain 700 -1900 Becquerels/gram of thorium-232; that is, at levels sufficiently high to warrant controls under the Radioactive Substances Act, if the works were operational today. Any uncontrolled disposal of these mantles could have resulted in soil contamination with the potential to cause harm to human receptors.

#### 5. Prevalence and Potential Impacts

It is thought that 5 gas mantle manufacturing sites were operating in the UK in the 1950s, all of which have now closed. The majority of these sites have the potential to pose radiological hazards, where dose rates could be in the millisievert range. For example, material with activity concentrations classifying it as Intermediate Level Radioactive Waste was identified at the East London site.

As thorium is an alpha emitter the main exposure pathway to human receptors is from the ingestion or inhalation of thoriated dusts. Thorium has a long half-life and will remain within the body for many years, accumulating in the bones, liver and kidneys.

Thorium is considered very immobile, as it is highly reactive and strongly adsorbed to soils and sediments; thus it is highly unlikely to migrate and affect offsite areas. For this reason, the potential for migration in the environment is low.

## 6. Implications for the Part 2A Regime

Concentrations of radioactive contaminants on former gas mantle works, including waste pits on such sites, are such that they are **capable of giving rise to** an individual effective dose of 3 millisieverts/year above local natural background levels under some scenarios.

## 7. References and further information

Department of the Environment. Industry Profile: Asbestos Manufacturing Works. 1995.

Department for Environment, Food and Rural Affairs. Historic practices in the UK which have utilised radioactive materials. Report DETR/RAS/00.005. 2001.  
<http://www.defra.gov.uk/environment/radioactivity/publications/complete/>

Public Protection Department, London Borough of Redbridge. Personal Communication. 2003.

JSP 32, Instructions for Radiation Protection MOD. 1999.

Drury NC. Remediation and restoration of a thorium and radium contaminated site. Radioactive Waste Management and Restoration Vol 19 247-261. 1995.

Environment Agency, Defra, Welsh Assembly Government. Indicators for Land Contamination. 2005

<http://publications.environment-agency.gov.uk/pdf/SCHO0805BJMD-e-e.pdf>

## DATA SHEET NUMBER E3: MEDICAL ESTABLISHMENTS

### 1. Background

Medical establishments include hospitals, hospices, research and development institutions, and teaching establishments (medical schools).

The first medical applications of radioactivity took place in France in 1901. Nuclear medicine is now practised in numerous hospitals, clinics and dental establishments throughout the UK.

It is worth noting that X-rays, the best known medical use of radioactivity, are not a potential source of contamination today because they are produced using electrical equipment, rather than radioactive sources. This was not the case historically.

### 2. Activities

The variety of radionuclides used, and the range of medical uses undertaken has increased steadily since the first medical application at the beginning of the twentieth century. Medical uses can be divided into two categories: diagnostic investigations (including imaging systems) and therapeutic procedures.

Diagnostic investigations include the use of radioactive tracer substances, which are combined with appropriate chemical compounds so that they accumulate in the organ under investigation. Radioactive tracers often have short half-lives and 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.

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

### 3. Waste Management

Radioactivity which has been administered to the body will usually be excreted and discharged to the sewage system at the hospital.

Other wastes comprising contaminated items of 'soft' medical equipment – swabs and dressings etc can be decay stored on-site and disposed of with conventional wastes. However, because of the potential for cross-contamination with pathogenic material, the wastes are more frequently incinerated either on the hospital premises or at a merchant incinerator.

Waste storage at hospital sites has been very closely controlled since the introduction of the Radioactive Substances Act in 1963. Prior to this, waste handling and storage, in outside compounds, may have taken place providing a small possibility of ground contamination.

### 4. Potential Contaminants

The most frequently used radionuclides identified in the 1993 UK nuclear medicine survey were technetium-99m; krypton-81m (gas); iodine-131; xenon-133 (gas); thallium-201 and tritium. However, many other radionuclides are used.

### 5. Prevalence and Potential Impacts

The vast majority of radionuclides used for medical purposes have a short half-life, typically measured in days or even, in the case of technetium-99, in hours. Persistence in the environment is negligible. However, tritium which is easily transported through the environment via a variety of pathways, will persist for decades. It does, however, have a low radiotoxicity and environmental concentrations are low.

Although a number of pathways for human dose uptake can be envisaged, all of them are considered unlikely. Doses from the inhalation or ingestion of airborne or water-borne tritium species represents perhaps the most likely pathway.

## 6. Implications for the Part 2A Regime

Concentrations of radioactive contaminants in waste streams from current and former medical establishments are such that they are **unlikely to be capable of** giving rise to an individual effective dose of 3 millisieverts/year above local natural background levels under any reasonable scenario.

## 7. References and further information

A history of the use of radioactive materials in medicine can be found at [www.curie.fr/curie/cdrom/present/histoe.htm](http://www.curie.fr/curie/cdrom/present/histoe.htm)

Administration of Radioactive Substances Advisory Committee. Notes for guidance on the clinical administration of radiopharmaceuticals and the use of sealed radioactive sources. 1998.

Titley JG, Carey AD, Crockett GM, Ham GJ, Harvey MP, Mobbs SF, Tournette C, Penfold JSS, Wilkins BT. Investigation of the sources and fate of radioactive discharges to public sewers. Research and Development Technical Report P288. Environment Agency. 2000.



## DATA SHEET NUMBER E4: MISCELLANEOUS SMALL USERS

### 1. Background

This data sheet deals with a variety of miscellaneous uses of radioactive materials by the 'small user' community; that is, users of radioactivity outside the nuclear industry. Major users and applications (e.g. radium luminising, general defence purposes, medical applications) are covered in separate data sheets of this profile.

Currently all such uses are covered by the Radioactive Substances Act permitting regime, but this legislation did not come into force until 1963. Registers of current premises using radioactive substances are held by the various environmental regulators, who also hold records of past permitted activities and sites.

### 2. Activities

Radioactive materials are widely utilised in the research sector, either to investigate the radioactive properties of materials and how they can be further utilised such as the continuing development of radiotherapy, or because the radioactive properties of an isotope allows certain measurements to be made such as the use of radio-tracers in the investigation of plant physiology.

Gamma radiography is the most common use of sealed sources, and this is used to assess castings, welds etc. Sources used for modern industrial gamma radiography normally comprise small sealed sources which are kept in metal shielded containers. These are often designed to double as transport containers and therefore comply with the relevant regulations for the transport of radioactive materials.

### 3. Waste Management

Sealed sources are generally sent for disposal at a recognised facility or returned to the manufacturer for re-work and recycling.

Open sources generally have a short half-life in the range of days or weeks. This is particularly true of radioisotopes used in the environment for tracer studies. Others, following use, are discharged directly to the environment as wastes.

Burial of wastes in-situ is not authorised today, but some wastes may have been buried local to factory premises before controls were introduced under the Radioactive Substances Act in 1963.

#### 4. Potential Contaminants

Potentially any radionuclide, but the principal ones of concern include radium species, tritium and carbon-14.

#### 5. Prevalence and Potential Impacts

The radiological risks to human health and the wider environment posed by small users of radioactivity will be dependent upon the radionuclides used and their method of disposal. Impacts, if they exist, are likely to be very localised. It is considered that sites which used radionuclides prior to appropriate regulation in 1963 are likely to pose the highest risks.

#### 6. Implications for the Part 2A Regime

For small user premises which have held a registration (for keeping and use of radioactive materials) or an authorisation (for accumulation and disposal of radioactive wastes) under the Radioactive substances Act are **unlikely to be capable of** giving rise to an individual effective dose of 3 millisieverts/year above local natural background levels. Premises which used radioactive materials or disposed of radioactive wastes prior to formal regulation under the Radioactive Substances Act are **capable of giving rise to** such a dose if the practice undertaken was known to involve an open source and/or local disposal in waste pits was known to have been practiced.

#### 7. References and further information

The Environment Agencies maintain publicly-available records on current registrations and authorisations. Historical records made under the Radioactive Substances Act 1993 are also available, dating back to the first Act in 1963.

## DATA SHEET NUMBER E5: UK NUCLEAR INDUSTRY

### 1. Background

Nuclear industry sites which are licensed under the Nuclear Installations Act 1965 (or under equivalent arrangements applying to certain MOD property) may contain radioactively contaminated land. Remediation activities on such sites are matters for the nuclear industry operator in question in consultation with the Health and Safety Executive. However, historical discharges from such sites may have led to off-site land contamination, possibly remote from the site itself. This data sheet deals with this eventuality.

The UK nuclear industry, both civil and military, has been in operation since the late 1940s. It can be conveniently classified into five groups, each with different characteristics in so far as discharges of radioactive wastes are concerned:

- Defence activities at Aldermaston, Burghfield, Devonport, Derby (Rolls Royce), Barrow, Faslane and Rosyth;
- Civil nuclear power generation at Hartlepool, Sizewell, Bradwell, Dungeness, Hinkley, Oldbury, Berkeley, Heysham, Windscale (Sellafield), Transfynydd, Wylfa, Torness, Hunterstone and Chapplecross;
- Civil nuclear fuel cycle at Capenhurst, Springfields and Sellafield;
- Waste disposal at Drigg;
- Research and miscellaneous facilities at Harwell, Winfrith, Windscale (Sellafield), Amersham, Cardiff and Dounreay.

### 2. Activities

Defence activities include research, development, manufacture and testing of nuclear weapons, the production of nuclear submarine fuel, and the maintenance of nuclear submarine reactors.

Civil nuclear power generation involves the production of electricity from nuclear fuel in a reactor and the storage of spent nuclear fuel in ponds or dry stores.

The civil nuclear fuel cycle involves the production of nuclear fuel, reprocessing of spent fuel, the enrichment of uranium hexafluoride, and the management of radioactive wastes arising from these activities.

One category of radioactive waste – Low Level Radioactive Waste (LLW) is disposed to sub-surface engineered vaults at the Drigg site in West Cumbria. Prior to 1990, most LLW was disposed of to shallow trenches on the site, which are now capped and landscaped.

Research and miscellaneous facilities include nuclear fuel characterisation, evaluation of different reactor types, radioactive waste assay and the manufacture of radiochemicals and radioactive sources.

### 3. Waste Management

Waste accumulation and storage on nuclear licensed sites is regulated by the Nuclear Installations Inspectorate of the Health and Safety Executive under the Nuclear Installations Act 1965. Waste is usually in solid form, in one of the main categories of radioactive waste (HLW, ILW and LLW). On some nuclear sites, there can be some limited storage of Very Low Level Radioactive Waste (VLLW). Some wastes are stored in liquid form.

Wastes in some of the lower categories, in some instances (more prevalent historically than today), have been stored in open areas with the possibility of leaching of radionuclides to the ground. Transport of such leached waste in groundwaters beyond the site boundary leading to off-site contamination can not be completely ruled out.

Discharges and transfers of radioactive waste from nuclear licensed sites are regulated under the Radioactive Substances Act 1993 by the Environment Agencies.

Excluding the case of the Drigg LLW disposal site, radioactive solid and liquid wastes are transferred from nuclear sites for disposal or destruction remotely. Such transfers are very limited, but include transfers to conventional landfill (under arrangements known as ‘controlled burial’) and to commercial incinerators. These wastes are not considered further in this data sheet; disposals are covered under the waste industry data sheets (D1-D4).

At the Drigg disposal site, compacted, and in a limited number of instances, loose, solid wastes are grouted into half-height iso containers and stacked in concrete lined vaults. This practice supersedes an earlier one (prior to 1990) in which loose wastes were tipped into open trenches, compressed and covered.

Direct discharges to the atmosphere occur from most sites.

Discharges to sewers and open waters (sea, tidal estuaries or inland rivers) occur from most sites. Surface water at the Drigg site is channelled, sampled and analysed prior to discharge to the Irish Sea.

#### 4. Potential Contaminants

A very large range of radionuclides are discharged to the environment via authorised atmospheric and liquid discharge routes. The principal contaminants are:

- Defence activities: tritium, uranium species and plutonium species;
- Civil nuclear power generation: tritium, caesium-137, carbon-14, sulphur-35 and argon-41;
- Civil nuclear fuel cycle: uranium species, thorium species, uranium and thorium decay chain daughters, plutonium species, tritium, carbon-14, cobalt-60 and fission products (principally caesium-137, strontium-90, technitium-99 and iodine species);
- Waste disposal at Drigg: any;
- Research and miscellaneous: any. For manufacturers of radioactive chemicals, carbon-14 and tritium are the most important radionuclides.

#### 5. Prevalence and Potential Impacts

The nuclear industry is nation-wide, but most of the significant sites are located in remote coastal areas.

Over a fifty year period, discharges to the environment have been made. Strict controls on discharges were introduced in 1963 when the first Radioactive Substances Act came into force. Subsequent to its introduction, there have been progressive and substantial reductions in discharges, such that they are now generally at least an order of magnitude lower than hitherto. The greatest discharges came from Sellafield and these peaked in the mid-1970s. Since that time discharges of some radionuclides have decreased by two or three orders of magnitude. The major potential impact will therefore be from the historical discharges of those radioisotopes which have a half-life longer than a few years, and which are known to persist in the environment.

Atmospheric discharges can result in deposition of radionuclides on land. Subsequently, there is a pathway back to human receptors via the food chain if the land in question is used for agriculture. There is a very substantial programme of analysis and sampling of such potentially contaminated land (soils and vegetation) in the areas surrounding nuclear licensed sites which indicates that environmental concentrations are very low, sometimes being indistinguishable from natural background.

There is a second pathway from such land, this being direct radiation. Again, direct monitoring shows that dose rates are extremely low.

Discharges to open waters can result in contamination of sediments. If dried out permanently, or temporarily (for instance when rivers recede due to seasonal variations in level), the resulting land contains slightly elevated levels of radioactive materials. Discharges from some sites to the sea have resulted in the contamination of shorelines (including sands and sea-washed turf).

Land contamination arising from liquid discharges can lead to pathways to human receptors of direct radiation and inhalation/ingestion of soils, or agricultural products grown on such soils. For the external pathway, there have been isolated instances of doses up to 0.1 millisieverts/year from contaminated beaches, assuming high human occupancy times. Some of the highest doses have arisen from living on houseboats in the Ribble and Wyre estuaries (about 0.15 millisieverts/year) as a result of external dose from sediments which have incorporated radionuclides discharged from Springfields and Sellafield. Recent doses are less than 0.1 millisieverts/year as a result of the reduction in occupancy times on the boats.

An assessment for human receptors who used sea-washed turf in gardens resulted in a calculated dose of 0.06 millisieverts/year. Most measured doses are significantly lower than this. Ingestion and inhalation pathways also give lower doses than those for direct radiation.

Another pathway to human receptors is the use of seaweed as a compost/fertiliser. Current dose assessments for agricultural uses of estuarine environments are based on current farming practices (sheep and cattle grazing). There is the potential for radionuclides to be transferred to other foodstuffs if the land is reclaimed for this use. However, salt concentrations may restrict such development.

In 2003 the terrestrial environment around each nuclear site gave rise to doses less than 0.05 millisieverts/year, the main pathways being groundshine (direct radiation) and ingestion of foodstuffs.

## 6. Implications for the Part 2A Regime

There is substantial evidence in the form of monitoring data and supporting radiological assessments to indicate that discharges (current and historical) from the nuclear industry are **unlikely to be capable of** giving rise to an individual effective dose of 3 millisieverts/year above local natural background levels.

## 7. References and further information

Environment Agency, Environment and Heritage Service, Food Standards Agency and Scottish Environment Protection Agency. Radioactivity in Food and the Environment. Annual publication.

Environment Agency and Scottish Environment Protection Agency public registers contain information on activities at nuclear licensed sites, in particular relating to prospective doses, historical discharges to the various media, and, in some cases, the environmental fate of radionuclides discharged from the site.

## **GENERAL DESCRIPTION OF RADIOACTIVE PHENOMENA**

This annex provides a general description of radioactive phenomena. More information about radioactivity can be found on the Health Protection Agency's website <http://www.hpa.org.uk/radiation/default.htm>

## **RADIOACTIVITY**

Radioactivity is a property possessed by radioactive substances 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 wider environment.

## **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.

## **RADIOACTIVITY AND RADIATION**

The atoms of a specific element 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.

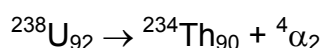


Not all combinations of protons and neutrons are stable. An unstable atom will try and reach a stable state by emitting energy in the form of radiation. This process is defined as decay and can result in an atom changing to become a different element. A decaying atom may form a number of radioactive 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 radiation. The radiation emitted by these processes is usually high-energy radiation which can have the effect of inducing ionisation in any target material (including human tissue). For this reason, the radiation is usually referred to as ionising radiation. The various types of ionising radiation 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:

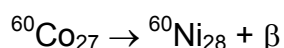


The notation above is conventional. For an isotope  ${}^a\text{B}_c$ ,  $a$  is the mass number, or the total number of protons and neutrons in the nucleus, and  $c$  is the atomic number, which represents the total number of protons.

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 lighter than alpha particles. They have a range of up to several metres 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 radiation is uncharged, has no mass and travels at the speed of light. Due to these properties, they are very penetrating and can travel up to several hundred metres in the 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 radiation only in the mechanism of production. Whereas gamma rays are produced in the nucleus, X-rays are produced by interaction in the electron surrounding the nucleus. While X-rays may be a product of radioactive decay they are usually created artificially when a high speed electron strikes a solid target.

## **NEUTRON RADIATION**

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

## **MEASURING RADIOACTIVITY**

Radioactivity in materials is measured by the number of atomic nuclei that decay in one second (or the number of nuclear disintegrations per second). The larger the number of decays per second, the more active is the material. 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 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.

## RADIOACTIVE 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  $1/8$  of 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

## 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.

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.

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, with a greater dose representing a higher risk of harm caused by the radiation. There are three ways of describing radiation dose:

The absorbed dose which is the measurement of the energy that is deposited in a material per unit mass from any interaction with radiation. It is measured in grays (Gy) with 1 gray equal to 1 joule per kilogram.

The equivalent dose which is the absorbed 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. It is measured in sieverts (Sv).

The effective dose, which is the sum of the weighted equivalent doses. The weighting takes into account the differing sensitivities of different organs. This allows the various dose equivalents in the body to be represented as a single number. This dose provides a broad indication of the detriment to health from any exposure to ionising radiation. It is measured in sieverts (Sv).

## **EXPOSURE PATHWAYS**

There are two main pathways of exposure of an individual to a radiation dose: exposure from external radiation; and internal exposure after an individual has ingested or inhaled radioactive material.

If an individual stands close to a source of radiation they could receive a radiation dose. 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.

The dose an individual could receive from the source can be reduced by restricting access 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.

An important property of ionising radiations, which is important in assessing the risk posed by radionuclides, is their ability to penetrate matter. The penetration depth of a particular radiation type increases with energy, but will vary for different radiation

types with the same energy. For equal energies, beta particles penetrate a greater depth than alpha particles, which can scarcely penetrate the dead outer layer of human skin, gamma radiation is most penetrative.

Therefore, pure alpha emitting nuclides are not hazardous unless taken into the body. Beta particles can penetrate a few centimetres of tissue so external radiation can be hazardous to superficial tissues, but not internal organs unless taken into the body. For gamma rays the degree of penetration depends upon the nature of the interaction with the tissue. They also have the ability to pass straight through the body and other materials. Nuclides that emit them can therefore be hazardous due to external or internal irradiation.

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.

## **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 outer space, radioactive elements naturally present in rocks and soils and in the food and drink that we eat. This natural background radiation is not usually considered when taking steps to reduce radiation exposure. All life forms have always been exposed to it, and furthermore, reductions are not generally practicable. The major exception to this is radon gas, which is a naturally-occurring gas resulting from the decay of minute amounts of uranium in soils in rocks. Exposure to radon gas in houses is known to lead to a significantly increased risk of lung cancer in the population. Guidance on the risks from radon, and its likely presence in different parts of the country is available from the Health Protection Agency.

## **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 experienced staff with knowledge of health physics. Using staff with experience and training in the use of radiation and dose rate monitors and the undertaking of surveys, is essential in an assessment of any contamination on a site. The experience and knowledge of health physics will allow these surveys to be undertaken in a safe manner. 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.

## **NORM**

The term naturally occurring radioactive material (NORM) is used to describe radioactive material which is naturally present in the earth's crust, and has not resulted from any anthropogenic activity such as weapons testing or energy production. Many activities described in the data sheets have had the effect, not of generating new radioactive material, but of concentrating naturally occurring radioactivity to a level higher than that found naturally.