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Historical land uses in England and Wales with the potential to cause land to be determined as radioactively contaminated

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Abstract

The purpose of this publication is to provide regulators, developers, consultants and other interested parties in England and Wales with guidance on those historical land uses that may have resulted in levels of activity being present in the land such that the land may now meet the legal definition of being radioactive contaminated land. This report updates a publication issued in 2006 by the Department for Environment, Food and Rural Affairs.

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This report from the PHE Centre for Radiation, Chemical and Environmental Hazards reflects understanding and evaluation of the current scientific evidence as presented and referenced in this document.

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Report version 1

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1 Introduction

Prior to the introduction of the 1960 Radioactive Substances Act that came into force in 1963, the management of wastes containing elevated levels of radioactivity was not subject to regulatory control. Consequently, before 1963, many industries managed all wastes in the same way regardless of their radioactive content. The historical disposal of wastes containing enhanced levels of radioactivity from many different types of industry has therefore left a legacy that may require management today.

In the UK, sites contaminated with radioactivity are managed within the statutory regimes for the identification and remediation of land contaminated with radioactivity made under Part 2A of the Environmental Protection Act 1990 (UK Government, 1990). Within the regime as applied in England and Wales, local authorities have a duty to inspect land in their area to identify sites that, in their current use, represent an unacceptable risk to health due to the presence of radioactivity. The trigger for a local authority to inspect land is when it considers that there are reasonable grounds for believing that land may be radioactive contaminated land. In the accompanying Statutory Guidance it is stated that ‘a local authority will have such reasonable grounds where it has knowledge of relevant information relating to (a) a former historical land use, past practice, past work activity or emergency’ or ‘(b) levels of contamination present on the land arising from a past work activity or emergency’ that are capable of causing lasting exposure giving rise to radiation doses above those set out in Paragraph 4.4 of that Guidance (BEIS, 2018).

To aid the identification of land where the radioactively contaminated land regime may need to be applied, this report presents a description of those historical land uses that had the potential to contaminate land with radioactivity. However, as the risk posed by radioactivity depends not only on the nature and activity concentration of the contaminants but also on the habits of the people potentially exposed, it is not possible in this report to state whether a specific area of land could meet the conditions for it to be determined as radioactive contaminated. Consequently this report only gives a subjective analysis of the possibility that exposure received today, from any reasonable use of the land to any radioactivity present as a contaminant, may result in doses above the criteria given in the Radioactive Contaminated Land Statutory Guidance (BEIS, 2018). To aid investigation and assessment of land by a local authority, this report also provides an overview of the potential form of any contamination, the key radionuclides likely to be present, and the exposure pathways most likely to exist today for each historical land use that could have led to contamination being present. In England and Wales, this report replaces an earlier publication on the same subject (Defra, 2006).

Section 2 presents an overview of the main historical land uses that had the potential to cause land to become contaminated with radioactivity. Section 3 summarises the information presented in Section 2, highlighting those historical land uses that have the greatest potential to cause land to meet the conditions for it to be determined to be contaminated.

2 Overview of historical land uses and their potential to cause land to be contaminated with radioactivity

2.1 Mineral mining and refining

The mining of minerals in the UK has occurred for many centuries. The extraction of metal ore is normally accompanied by the extraction of large quantities of surrounding rock which has no inherent value. In most cases this rock is discarded on site although the location and size of the spoil heaps varies from site to site depending upon local factors such as land availability and topography. For some deeper mines, spoil may have been used to infill nearby valley features. As all geology contains varying levels of naturally occurring radionuclides from the uranium and thorium radioactive decay chains, the disposal of spoil may have inadvertently resulted in an elevation in the level of radioactivity present in local soil. At a few locations, heavy rain has resulted in the movement of loose spoil to areas outside the original site. Where this has occurred, locations where dusts and other loose material can accumulate, such as drainage ditches or temporary surface water bodies, may have debris or sediment present with enhanced concentrations of radioactivity.

Refinement of some ores involves a thermal process that can result in the production of additional wastes that may also have elevated levels of radioactivity. For example, isotopes of lead (Pb) and polonium (Po), present in small quantities in coal, are often released to atmosphere attached to small particulates when coal is burnt. Although filters are often used to reduce the number of particulates being released to atmosphere the collected ash, which may have been disposed of locally as a waste material, is likely to have a higher activity concentration of some radionuclides compared to the original coal.

Smelting also produces slag which is a glass-like by-product left over after the desired metal has been removed. Depending on the refining process used, this slag may contain enhanced quantities of some radionuclides when compared to the original ore. Although slag is often treated as a waste product it can have properties that allow it to be used in construction. For example, slag is often used as rail track ballast or in paving or road construction. It is therefore important that the presence of enhanced levels of radioactivity where slag may have been used are also considered when identifying land potentially contaminated with radioactivity.

Mineral extraction from other ores requires a chemical process that may also result in the concentration of naturally occurring radionuclides in waste material. For example, phosphate rich rocks containing naturally occurring radionuclides from the uranium and thorium radioactive decay chains have long been used in fertilisers and detergents. During processing phosphate rocks were dried, crushed, and then fed into a reactor along with sulphuric acid. This process forms calcium sulphate, commonly known as gypsum or phosphogypsum, which contains most of the radioactivity from the phosphate rock. On some sites the gypsum was disposed of as slurry to sea-pipelines although at other sites, particularly the smaller ones, the waste gypsum slurry was pumped into gypsum ponds for storage and drying prior to disposal to an on-site landfill. Within such ponds, many of which were landscaped following use, radionuclides may have accumulated in sediment. This method of production ceased in the UK in the 1980s as more economically viable processes were identified.

Of the various mineral mining operations that have occurred in the UK, the extraction of uranium ore and its processing has the greatest potential to cause radioactive contamination of land. This is due to the potentially high activity concentration of radium and its radioactive decay products in wastes that were frequently disposed of to spoil heaps. Although no mining for uranium currently takes place in the UK it did occur in a small number of mines, mainly located in south west England, prior to the early twentieth century.

2.2 Radium luminising and associated processes

Use of radioluminescent substances to facilitate the reading of instruments such as watches and dials in conditions of low ambient light was one of the earliest uses of radioactive materials. The use of luminising paint containing radium-226 (^{226}Ra) occurred mainly between the 1920s and 1960s when it was phased out in favour of other intrinsically safer radionuclides such as tritium and promethium-147 (^{147}Pm). A major user of radium paint was the military, particularly during the Second World War. Consequently, many military facilities had specialised buildings where radium paint was stored and used. Although the production of radium paint and the process of radium luminising did take place within large premises, a cottage industry also developed where painting was carried out by workers in their homes.

The primary waste products from radium luminising included empty paint vials and brushes. Maintenance of old equipment also occurred and, prior to re-painting, the removal of old luminising residues from instruments undergoing refurbishment was often required. At locations where equipment was repaired or maintained, waste may have also include radium paint scrapings as well as whole or parts of luminised items. Prior to controls being imposed under the Radioactive Substances Act in 1963, wastes associated with radium luminising were either buried directly on-site or incinerated and the residues buried or used in construction projects.

In addition to wastes created during radium luminising activities, large numbers of redundant aircraft were also disposed of after the Second World War. In many cases these aircraft were incinerated on site to reduce the volume of waste prior to burial (COMARE, 2014). As aircraft were often incinerated intact, waste created by their incineration included damaged or intact instruments painted with radium.

As radium was applied as a liquid, buildings where luminising activities occurred are frequently found to be contaminated to varying degrees due to spills as well as poor housekeeping. Fixtures and fittings such as workbenches, walls and floors, sinks and associated pipe work, light switches, door handles, window sills, storerooms and cloakrooms, could all be potentially contaminated. Areas external to buildings where radium luminising took place, including those close to windows, may also have been affected by informal disposal of waste paints.

Identification of sites where wastes from radium luminising and instrument maintenance were disposed to is difficult since, in many cases, adequate records were not kept. One of the main sources of information allowing identification of potential incineration and burial sites is likely to be local knowledge. Non-intrusive techniques such as geophysical surveys may identify buried structures that may have been associated with luminising activities such as drainage systems, as well as areas where waste disposal may have occurred. However, non-intrusive identification of enhanced levels of radioactivity in areas where luminised waste disposal may have occurred is often difficult due to the depth such waste was often buried at.

2.3 Energy production facilities

Prior to the discovery and development of the UK’s natural gas fields in the 1960s and 1970s, many buildings were heated with town (or manufactured) gas. Although most town gas used in the UK was synthesised from coal, a small fraction was generated using a reaction of various hydrocarbon feedstocks with steam in the presence of a catalyst. Most of the sites where this process occurred used nickel oxide as the catalyst but a few used uranium oxide. As the production of town gas predated the Radioactive Substances Act, information on how waste uranium oxide was disposed of is not readily available although on most sites it is likely that such waste would have been disposed of with other scrap into an on-site landfill.

The extraction of oil and gas from underground reservoirs mobilises naturally occurring radionuclides which can either be deposited as a radium-bearing scale in equipment or become concentrated in sludge. Although descaling operations in the UK today mainly take place in the North of Scotland, and is carried out under regulatory control, there is the possibility that other sites have been used in the past where less stringent controls were in place. For example, exploitation of oil shales from the Kimmeridge shales of southern England has occurred since the mid nineteenth century and no information exists as to where or even if their equipment was descaled.

Coal was a major contributor to the UK’s electricity production program from the early twentieth century until the early 2010’s (National Statistics, 2018). All coal contains low concentrations of naturally occurring radionuclides and its combustion releases some radionuclides to the atmosphere and concentrates other radionuclides in ash. Collected ash may have been accumulated at coal-fired power stations pending final disposal, been disposed of on-site in above ground landscaped features, been sent to landfill, or used in road embankments and other landscaping projects. Fly ash generated by the coal-fired power production industry has also been widely used as a supplementary material in the production of Portland cement.

The level of radioactivity present in wastes produced by a range of non-nuclear industries is generally low enough that there is little chance that land affected by those industries would require control under the radioactive contaminated land regime.

2.4 Waste disposal facilities

Disposal to landfill of wastes containing radioactivity is today controlled through regulation and any exposure likely to be received by the public from such disposals is relatively low. However, disposal to landfill of wastes containing radioactivity in the past was more widespread than at present, especially as radioactive wastes were not routinely segregated from other wastes prior to disposal. Landfill sites close to facilities where radioactive materials were used or generated prior to the introduction of the Radioactive Substances Act in 1963 have the greatest potential for unrecorded disposal of radioactive waste.

The absence or disintegration of containment barriers in landfills mean that leachate can migrate off-site. This leachate may contain highly mobile radionuclides like tritium. As leachate created by historical landfills is unlikely to have been treated prior to escaping into the environment, there is the potential for contamination of local groundwater or surface water and its sediments. Gases are also produced by landfills mainly by the action of microorganisms on waste. Such gases may include radioactive forms of carbon if waste containing such radionuclides were placed into the landfill. In addition, the radioactive decay of some radionuclides like radium produces radioactive gases, in this case radon. Whilst radioactivity in landfill gas or radon is not normally a problem if it is released to the open air, such gases can concentrate inside buildings constructed either above or near to the landfill. In some cases, the risk posed by those gases may require some form of management. In addition, depending on the characteristics of the waste and its method of disposal, areas of enhanced radioactivity may exist within the body of the landfill. If the contents of a landfill were to be disturbed, as may occur during development of the site, then disposed material may end up in locations where members of the public are able to access it.

Incinerators have been used for the disposal of domestic and municipal wastes since 1876. Wastes sent to incinerators can and do include radioactive materials although the amount of radioactive material being sent to any incinerator in the UK has been regulated since 1963. During incineration, any radionuclides present in the waste are concentrated in either the ash or off-dusts. Ash or dust produced by incineration is normally landfilled but it may also be used as road sub-bases or in paving.

A small number of scrap yards have inadvertently received high activity industrial sources or metals contaminated with radioactivity such as pipework containing radium-bearing scales. Procedures in place today mean that any contaminated scrap arriving at a scrap yard is suitably managed to prevent both the material being recycled as well as contamination of the scrap yard. However, in the past contaminated scrap may not have been either identified or managed in such a way to prevent further contamination. At some scrap yards, contaminated metal was collected in drums or in heaps on open ground prior to its disposal to landfill or, for sealed sources which have far higher levels of radioactivity, to a long-term storage facility under the care of a specialist waste contractor. Although there is potential for scrap metal containing radionuclides to be present in a very low number of scrap yards, this material is generally in the form of a solid and as such the ground at scrap yards are unlikely to be contaminated with radioactivity.

2.5 Miscellaneous uses of land

The small user sector consists of those users of radioactivity outside the nuclear industry and includes research, industrial and medical establishments. Prior to 1963, some radioactive waste produced by small users was stored and disposed of on-site. As such practices were carried out by each site on an ad-hoc basis it is not possible, except in a few cases, to predict which sites have the potential to contaminate land with radioactivity. In addition, in the early twentieth century, research programs existed at several universities, such as Manchester and Cambridge, which made use of unsealed radioactive sources. Spills and the emission of radioactive vapours are known to have contaminated rooms and furnishings, including walls and benches, with radioactivity (Jones et al, 2010).

Gas mantles were widely used for lighting from the late nineteenth century until the widespread introduction of electric lighting in the early twentieth century. The mantles were made by the impregnation of cloth with nitrate of thorium and other metals. Wastes from the production of gas mantles, as well as the mantles themselves, were likely to contain radioactive thorium and its decay products. During the manufacture of gas mantles it was common practice to dispose of thorium contaminated wastes through burial at the manufacturing site or in nearby landfills. The level of radioactivity which could be present at a former gas mantle production site is such that, if the site has not been remediated correctly, it could meet the criteria for being determined as radioactive contaminated land. However, the area affected by radioactivity from gas mantle production is likely to be limited as thorium is very immobile in the environment.

Munitions utilising depleted uranium (DU) have been manufactured at a very small number of sites in the UK. Wastes produced during the manufacture of DU penetrators need to be handled carefully because of their pyrophoric nature and are not disposed of at the manufacturing sites. Limited firing of DU weapons has also occurred in the UK since the 1960s; firing ranges where DU munitions have been tested all remain under MoD ownership.

Land contaminated with radioactivity is also present on sites that are licensed under the Nuclear Installations Act 1965 (UK Parliament, 1965). Such sites include those involved in developing and maintaining the UK's nuclear deterrent as well as sites where research is conducted, where waste management has or is taking place, and sites involved in the manufacture of nuclear fuel and production of electricity. The management of such land is a matter for the licence owner in consultation with the appropriate regulator and so its management is excluded from the contaminated land regime under section 78YB of the Environment Protection Act 1990. Outside the area defined by a site licence, doses to members of the public from the routine discharge of radioactivity are far below the level used to determine land as being radioactively contaminated; this is confirmed by independent monitoring (Environment Agency et al, 2018).

2.6 Key radionuclides and exposure pathways

In many of the land uses discussed in this report, potential contamination of land by radioactivity involves members of the naturally occurring radioactive decay chains headed by uranium-235 (^{235}U), uranium-238 (^{238}U) and thorium-232 (^{232}Th). Radiation emitted by radionuclides within these radioactive decay chains include both alpha and beta particles and gamma rays. With respect to the health risk posed by radiation, alpha and beta particles are mainly of concern if they are emitted by radionuclides located inside the body, for example after their ingestion or inhalation. However, highly energetic beta particles may also pose a risk if they are emitted by radionuclides located near to the body. Gamma radiation can travel a considerable distance in air and can therefore pose a risk when emitted by radionuclides located at some distance from the body.

Inhalation of radioactivity can occur when radioactive gases are produced, especially when such gases concentrate inside buildings. This pathway is particularly important with respect to the production of radon gas following disposal of radium containing wastes onto land which has subsequently been built on. Inhalation of suspended dusts containing radioactivity may also result in a radiation dose although this is pathway is often only important when direct disturbance of dry ground occurs. Some historical industrial sites, including former MoD sites such as airfields, have been converted to farmland and the uptake of radioactivity by crops is possible. In addition, some domestic food may be grown in gardens or allotments created on former industrial sites. However, unless a significant proportion of an individual's diet comes from an area contaminated by radioactivity, the dose from consuming food grown on that land is likely to be relatively low. Consequently, especially for younger children, the intake of radioactivity by ingestion is mainly associated with the inadvertent ingestion of soil.

Many radionuclides likely to be present in the ground because of historical activities are relatively immobile in soil. Although these radionuclides may eventually reach groundwater this process is likely to take a very long time and include a significant decrease in activity concentration due to dilution and dispersion. Any water entering the public mains water supply comes from many sources and is regularly checked to make sure that any radioactivity naturally present in the water remains low. However, water extracted privately may come from a single source that, if close to or within a large area of contamination, may contain elevated levels of radioactivity.

If discrete items such as radium painted equipment or flakes of radium paint were disposed of, then it is possible that an individual may encounter them when using the land. As these items can contain relatively high levels of radioactivity, the resulting dose could be significant if those items are placed against the skin for several hours or if they are ingested. However, the probability of this occurring is likely to be low unless the item is visible and possesses features that would encourage someone to pick it up.

3 Summary of historical land uses with the potential to contaminate land to levels where harm could be caused

Section 2 discusses many land uses that had the potential to contaminate land with radioactivity. However, many of these land uses are likely to have resulted in levels of radioactivity far below that for which harm, as defined in the associated Statutory Guidance, would be caused (BEIS, 2018). To aid local authorities identify those historical land uses that had the greatest chance of causing radioactive contamination to be present at levels at which the radioactive contaminated land regime may need to be applied, the information discussed in Section 2 is summarised in Tables 1 and 2.

Table 1 summarises those historical land uses that had the greatest potential to contaminate land to an extent that the radioactive contaminated land regime might need to be applied. Table 2 summarises those historical land uses that could have resulted in radioactive contamination being present in land but where the level of contamination is likely to be below the thresholds for which the contaminated land regime might need to be applied. However, as each site has its own unique characteristics such as the specific industrial process used at the site and how that may have changed with time; whether any remedial or other activities that could have affected the level of contamination have been undertaken in the past; and the location of people or other relevant receptors with respect to the contamination, it is important that the magnitude of harm posed by any contamination is assessed on a site by site basis.

For each land use given in Tables 1 and 2, information is presented on the potential contamination process, the likely form of the contamination, the key radionuclides and main exposure pathways likely to be present. With respect to radioactive decay chains, the following nomenclature is used in Tables 1 and 2 to denote which key radionuclides are assumed to be present:

a ‘Any’ indicates that a wide range of radionuclides may be present making identification of key radionuclides impossible

b ^{238}U+ includes all members of the radioactive decay chain headed by ^{238}U, principally ^{238}U, ^{234}Th, ^{234m}Pa, ^{226}Ra, ^{222}Rn, ^{214}Pb, ^{214}Bi, ^{210}Pb, ^{210}Po

c ^{235}U+ includes all members of the radioactive decay chain headed by ^{235}U, principally ^{235}U, ^{231}Th, ^{231}Pa, ^{227}Ac, ^{227}Th, ^{223}Ra, ^{211}Pb, ^{211}Bi

d ^{232}Th+ includes all members of the radioactive decay chain headed by ^{232}Th, principally ^{232}Th, ^{228}Ra, ^{228}Ac, ^{228}Th, ^{224}Ra, ^{212}Pb, ^{212}Bi, ^{208}Tl

e ^{226}Ra+ includes all members of the radioactive decay chain headed by ^{226}Ra, principally ^{226}Ra, ^{222}Rn, ^{214}Pb, ^{214}Bi, ^{210}Pb, ^{210}Po

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Table 1 Uses of land with the potential to contaminate land with radioactivity to levels where harm is caused

Process	Contamination mechanism	Contamination form	Key radionuclides	Main exposure pathways*	
Uranium mining	Disposal of rock spoil#	Spoil rock	^{226}Ra+	External irradiation Food consumption	Inhalation of radon
Rare earth processing	Disposal of inert waste	Soils Furnace slag Pipe scale	^{238}U+, ^{235}U+, ^{232}Th+	External irradiation Food consumption	Inhalation of dust Inhalation of radon
Radium luminising works	Disposal on site of inert waste Disposal of liquid waste to drains Paint spills in buildings	Soils Buildings, foundations Waste drainage systems Discrete items	^{226}Ra+	External irradiation Food consumption Inhalation of radon	Skin contact with items Ingestion of items
Incineration of redundant equipment by MoD	Incineration of inert wastes Burial of clinker# Use of clinker in paving#	Ash and soils Clinker in paving Discrete items	^{226}Ra+	External irradiation Food consumption Inhalation of radon	Skin contact with items Ingestion of items
MoD maintenance facilities	Disposal on site of inert waste Disposal of liquid waste to drains Paint spills in buildings Use of waste to infill ground#	Soils, clinker in paving Buildings, foundations Waste drainage systems Discrete items	^{226}Ra+	External irradiation Food consumption Inhalation of radon	Skin contact with items Ingestion of items
Municipal landfill sites	Disposal of inert waste	Ash and soils Discrete items Miscellaneous items	Any	External irradiation Food consumption Ingestion of items	Inhalation of dust Inhalation of radon Skin contact with items
Gas mantle production	Disposal on site of inert waste	Soils Discrete items	^{232}Th+	External irradiation Food consumption Ingestion of items	Inhalation of dust Skin contact with items
Research establishments	Spills in buildings Disposal of liquid waste to drains Contamination of equipment	Buildings Furnishings and equipment Waste drainage systems	Any	External irradiation Food consumption Ingestion of items	Inhalation of dust Inhalation of radon Skin contact with items
Miscellaneous small users	Disposal on site of inert waste and sealed sources	Soils Sealed sources	Any	External irradiation Food consumption Ingestion of items	Inhalation of dust Inhalation of radon Skin contact with items

* Based on the current use of the land being either agriculture, recreation or residential

Some rock spoil and clinker is known to have been used at locations remote from the waste producing site (e.g. in landscaping, rail track ballast or coastal reclamation projects).

Table 2 Uses of land which are unlikely to have the potential to contaminate land with radioactivity to levels where harm is caused

Process	Contamination mechanism	Contamination form	Key radionuclides	Main exposure pathways*	
Metals mining	Disposal of rock spoil#	Spoil rock	$^{238}U+$, $^{235}U+$, $^{232}Th+$	External irradiation Food consumption	Inhalation of dust Inhalation of radon
Metals refining	Collection and disposal of ash Disposal on site of inert waste Sediment in settling ponds	Ash and soils Furnace slag	$^{238}U+$, $^{235}U+$, $^{232}Th+$	External irradiation Food consumption	Inhalation of dust Inhalation of radon
Depleted uranium munitions manufacture and testing	Manufacturing swarf Fired munitions	Discrete items	^{238}U	External irradiation Ingestion of items	Inhalation of dust Skin contact with items
Oil and gas facilities	Scale from pipes and equipment Discarded equipment	Pipe scale	$^{226}Ra+$	External irradiation Food consumption	Inhalation of radon
Coal-fired power stations	Collection and disposal of ash and dust	Ash and soils	$^{238}U+$, $^{235}U+$, $^{232}Th+$	External irradiation Food consumption	Inhalation of dust Inhalation of radon
Town gas industry	Disposal on site of wastes	Soils	^{238}U	External irradiation	Inhalation of dust
Incinerators	Collection and disposal of ash and dust	Ash and soils	Any	External irradiation Food consumption	Inhalation of dust Inhalation of radon
Scrap recycling	Disposal on site of inert waste	Discrete items	Any	External irradiation Food consumption Ingestion of items	Inhalation of dust Inhalation of radon Skin contact with items
Phosphate industry	Disposal on site of inert waste	Soils	$^{226}Ra+$	External irradiation Food consumption	Inhalation of radon

* Based on the current use of the land being either agriculture, recreation or residential

Some rock spoil and clinker is known to have been used at locations remote from the waste producing site (e.g. in landscaping, rail track ballast or coastal reclamation projects).