A Study on the Transport of Naturally-Occurring Radioactive Material

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ABSTRACT

Some materials that are used in various industrial processes, or generated as by-products or wastes, contain naturally-occurring radionuclides in concentrations that can be radiologically significant. If the concentration exceeds certain levels these materials would be subject to regulatory control during transport. This study examines the transport of such materials in the United Kingdom and assessments have been made of the radiological impact of these transport operations. It was found that the transport of such materials in the UK gives rise to very low radiological consequences. The International Atomic Energy Agency has initiated an international coordinated research programme to examine the transport of naturally-occurring radioactive material and this study is a contribution to that research.

This study was funded by the Department for Transport.

Approval: April 2008
Publication: April 2008
£13.00
ISBN 978-0-85951-615-0

This work was undertaken under the Environmental Assessment Department's Quality Management System, which has been approved by Lloyd's Register Quality Assurance to the Quality Management Standards ISO 9001:2000 and TickIT Guide Issue 5, certificate number 956546.

EXECUTIVE SUMMARY

Some materials that are used in various industrial processes, or generated as by-products or wastes, contain naturally-occurring radionuclides in concentrations that can be radiologically significant. If the activity concentration and activity in the consignment exceed certain levels these materials would be subject to regulatory control during transport. This study examines the transport of such materials in the United Kingdom and, where appropriate, assessments are made of the radiological impact of these transport operations. It was found that the transport of such materials in the UK gives rise to very low radiological consequences. The most significant movements of naturally occurring radioactive materials are items contaminated with scales associated with the oil and china clay industries. The study found that the annual dose to transport workers from the transport of these materials is less than 0.1 mSv. Estimates of the exposure of members of the public from these movements showed that the maximum annual dose would be much less than 0.001 mSv. The large scale transport of other industrial materials containing natural radionuclides was found to be outside the scope of the transport regulations due to the low activity concentration of those radionuclides. Never the less, the study included an assessment of the radiological impact of these movements. It was concluded that the maximum annual dose to a transport worker would be less than 0.2 mSv, and the annual dose to a member of the public would be much less than 0.001 mSv.

The International Atomic Energy Agency has initiated an international coordinated research programme to examine the transport of naturally-occurring radioactive material and this study is a contribution to that research.

CONTENTS

1 INTRODUCTION

Many natural materials that are used in various industrial processes, or which are generated as wastes or by-products of some industrial operations contain naturally-occurring radionuclides. The acquisition, use and disposal of these naturally occurring radioactive materials (NORM) will in most cases involve transport by one or more modes. Many such materials have very low activity concentrations and may be exempt from, or outside the scope of, the transport regulations.

The Glossary contains some descriptions and definitions of a number of technical terms that are used in this report. The dose quantity used throughout this report is effective dose and is abbreviated to dose. Sub multiples of the unit of dose, the Sievert, are described in the Glossary.

2 APPLICATION OF THE TRANSPORT REGULATIONS TO NORM

2.1 Exemption conditions

The standards of safety for the transport of radioactive material are set by the International Atomic Energy Agency (IAEA). The IAEA publishes Regulations for the Safe Transport of Radioactive Material (IAEA, 2005), and the standards embodied in those regulations are given effect in Great Britain by national legislation (GB Parliament, 2007). The IAEA transport regulations define radioactive material as material that contains radionuclides where both the activity concentration and the total activity in the consignment exceed the respective exemption values for those radionuclides, which are listed in the IAEA regulations. Therefore, if either value is not exceeded then such material is exempt from the transport regulations.

The regulations apply to radioactive material such as ores containing natural radionuclides which are used for purposes involving the extraction of those radionuclides, in particular uranium for use in nuclear fuel. However, there are natural materials which contain elevated concentrations of natural radionuclides, but which are not used for the extraction of those radionuclides. Controls on the transport of these materials may be necessary for radiation protection purposes if the radionuclide concentration is high enough. The scope of the regulations includes such materials containing natural radionuclides at concentrations a factor of 10 above the exemption concentrations. Regulation 107(e) (IAEA, 2005), states:

"The Regulations do not apply to:

(e) natural material and ores containing naturally occurring radionuclides that are either in their natural state, or have been processed only for purposes other than for the extraction of the radionuclides, and that are not intended to be processed for the use of these radionuclides, provided that the activity concentration of the material does not

exceed 10 times the values specified in para. 401(b), or calculated in accordance with paras 402 – 406;"

Paragraph 401 of those regulations (IAEA, 2005) refers to a table listing the exemption concentrations, in Bq g^{-1}, for each radionuclide. The radionuclides present in NORM are ^{40}K, and the members of the ^{238}U, ^{235}U and ^{232}Th decay series. The most relevant radionuclides are listed in Table 1, together with their listed exemption concentrations, and values obtained by multiplying those concentrations by 10. Where there is a decay chain in secular equilibrium, the listed concentrations apply to the radionuclide concentration of the head of the decay chain. In natural materials uranium and thorium are often in secular equilibrium with their decay products and so the values for U(nat) and Th(nat) apply. However when these materials are subjected to chemical or physical processing this equilibrium is likely to be disturbed and therefore the individual exemption concentrations of each radionuclide need to be considered separately. The material is then treated as a mixture as described in the regulations (IAEA, 2005).

TABLE 1 Exemption values for some natural radionuclides

Radionuclide	Exemption concentration, Bq g^{-1}	10 x Exemption concentration, Bq g^{-1}
U(nat)[1]	10^0	10^1
Th(nat)[1]	10^0	10^1
^{238}U	10^1	10^2
^{234}U[2]	10^2	10^3
^{230}Th	10^0	10^1
^{226}Ra[3]	10^1	10^2
^{232}Th	10^1	10^2
^{228}Ra[3]	10^1	10^2
^{228}Th	10^0	10^1
^{235}U[3]	10^1	10^2
^{231}Pa	10^0	10^1
^{227}Ac	10^{-1}	10^0
^{210}Pb[3]	10^1	10^2
^{210}Po	10^1	10^2
^{40}K	10^2	10^3

1. Assuming all decay products are present in secular equilibrium.

2. For e.g. UO_3.

3. Including short lived decay products.

2.2 Regulatory considerations for NORM transport

This study is primarily on the transport of NORM materials that are not intended to be processed for the extraction of the natural radionuclides they contain. These materials will therefore be outside the scope of the regulations if the radionuclide concentrations do not exceed the values in the third column of Table 1. Materials for which those values are exceeded will typically be transported as Low Specific Activity (LSA) material. The

categories of LSA material make use of the A_2 values for the relevant radionuclides in the material, where the A_2 value is the radionuclide-specific content limit for Type A packages for non-special form material. Specifically, in relation to NORM, Regulation 226 (IAEA, 2005) places the following materials in three categories of LSA.

LSA-I

- Uranium and thorium ores and concentrates of such ores, and other ores containing naturally occurring radionuclides which are intended to be processed for the use of these radionuclides.
- Natural uranium, depleted uranium, natural thorium or their compounds or mixtures, provided they are unirradiated and in solid or liquid form.
- Other radioactive material in which the activity is distributed throughout and the estimated average specific activity does not exceed 30 times the value for the exempt concentration.

Materials of the third type above could apply to NORM for example in the case of radium contaminated wastes. Regulation 226 (IAEA, 2005) also includes in LSA-I radioactive material for which the A_2 value is unlimited, but however, this would only apply to some rare natural radionuclides (such as ^{147}Sm) that need not be considered further in relation to NORM.

LSA-II

- Material in which the activity is distributed throughout and the estimated average specific activity does not exceed 10^{-4} A_2 g^{-1} for solids, and 10^{-5} A_2 g^{-1} for liquids.

LSA-III

- Solid material (excluding powders) in which the radioactive material is distributed throughout in a solid compact binding agent, and in which the estimated average specific activity does not exceed 2 10^{-3} A_2 g^{-1}.

If the NORM is attached to the surface of a non-radioactive solid object, that item may be transported as a Surface Contaminated Object (SCO). The two categories of SCO are defined in Regulation 241 (IAEA, 2005). The contamination limits for these are summarised below.

SCO-I

a) Non-fixed contamination, accessible surfaces: 4 Bq cm^{-2} for beta and gamma emitters and low toxicity alpha emitters, or 0.4 Bq cm^{-2} for all other alpha emitters.

b) Fixed contamination, accessible surfaces: 10^4 times the respective limits above.

c) Fixed plus non-fixed contamination, inaccessible surfaces: as b) above.

SCO-II

a) Non-fixed contamination, accessible surfaces: 400 Bq cm^{-2} for beta and gamma emitters and low toxicity alpha emitters, or 40 Bq cm^{-2} for all other alpha emitters.

b) Fixed contamination, accessible surfaces: 8 10^5 Bq cm^{-2} for beta and gamma emitters and low toxicity alpha emitters, or 8 10^4 Bq cm^{-2} for all other alpha emitters.

c) Fixed plus non-fixed contamination, inaccessible surfaces: as b) above.

While most NORM are transported as LSA and SCO materials, either unpackaged or in industrial packages, in some circumstances some of these materials might also be transported in excepted or Type A packages.

3 ACTIVITY CONCENTRATIONS OF NORM

3.1 Industrial uses

Naturally occurring radionuclides are present in almost all rocks and soils. The activity concentration of these radionuclides varies over many orders of magnitude. Natural materials are extracted and used for a number of industrial processes. In some of these operations the natural radionuclides can become further concentrated as a result of chemical processes. The main NORM materials that are transported in the UK are described below.

3.1.1 Coal and coal ash

The world average concentrations of ^{40}K, ^{238}U and ^{232}Th in coal are estimated, respectively, to be 0.05, 0.02 and 0.02 Bq g^{-1} (UN, 1988). Those radionuclides can be concentrated in coal ash, but the concentrations are still well below the exemption values. Radionuclide concentrations in UK coal are also low, the typical ^{226}Ra concentration being 0.015 Bq g^{-1} (Wan and Wrixon, 1988). Another study on coal samples from regions throughout the UK found average concentrations of ^{238}U, ^{232}Th and ^{40}K of, respectively, 0.0145, 0.0125 and 0.15 Bq g^{-1} (Salmon et al, 1984). Average concentrations for ash samples from a number of power stations (Wan and Wrixon, 1988; Beck, 1989) are shown in Table 2, along with the exemption concentrations.

TABLE 2 Natural radionuclide concentrations in coal and coal ash

Material	Source (power station)	Average concentration, Bq g^{-1}		
		^{226}Ra	^{232}Th[2]	^{238}U[2]
Coal[1]		0.015	0.02 (0.01-0.2)	0.02 (0.01-0.6)
Coal ash	Didcot	0.01	0.063	-
	Carmarthen Bay	0.072	0.053	-
	Ratcliffe-on-Soar	0.082	0.057	-
	Drax	0.098	0.070	-
	Eggborough	0.105	0.094	-
Exemption concentration, Bq g^{-1}		*10*	*1*[3]	*1*[3]

1. Ranges given in brackets.

2. Assumed to be in secular equilibrium with decay products in coal.

3. Values for Th(nat) and U(nat). The exemption concentration for both ^{232}Th and ^{238}U is 10 Bq g^{-1}.

Concentrations of some radionuclides are enhanced in the fly ash collected at the stations. In particular, concentrations of ^{210}Pb and ^{210}Po can range up to 2 Bq g^{-1} (UN, 1982). However these data and those presented above show that the concentrations of natural radionuclides in coal and coal ash are well below the exemption values.

3.1.2 Iron and steel production

Iron and steel production use iron ore, limestone and coal which contain low levels of natural radionuclides. However, the production process can result in some concentration of these radionuclides in the fuel ash, slag and dust from the sintering process. These by-products of the production process can be used in road building or other building materials, or disposed of at landfill sites.

Iron ore contains ^{238}U at a concentration of about 0.015 Bq g^{-1} (Harvey, 1999), similar to that in coal, which is approximately 0.02 Bq g^{-1} (UN, 1988). Dust collected from the sintering of iron ore contains elevated levels of ^{210}Pb and ^{210}Po, but at concentrations well below the exemption values (Ewers, 2007). Typical concentrations of natural radionuclides in the wastes, used in an assessment of the radiological impact of iron and steel production (Crockett et al, 2003), are shown in Table 3.

TABLE 3 Activity concentrations in materials from steel production

Radionuclide	*Exemption concentration, Bq g^{-1}*	Activity concentration, Bq g^{-1}	
		Slag	Landfill wastes
^{238}U	*10*	0.088	0.9
^{234}U	*100*	0.088	0.9
^{230}Th	*1*	0.088	0.9
^{226}Ra	*10*	0.088	0.9
^{232}Th	*10*	0.049	0.45
^{228}Ra	*1*	0.049	0.45
^{228}Th	*1*	0.049	0.45
^{235}U	*10*	0.004	0.04
^{231}Pa	*1*	0.004	0.04
^{227}Ac	*0.1*	0.004	0.04
^{210}Pb	*10*	n/s	0.9

n/s. Not specified as almost all Pb and Po, being volatile, are emitted from the slag.

The typical activities of radionuclides in both types of wastes from steel manufacture are therefore below the exemption concentrations. Although the activity concentrations of some of the radionuclides in the landfill wastes may approach the exemption values, they are well below the concentrations that would require the application of the transport regulations.

3.1.3 Building materials

Natural radionuclides in rocks and clays become incorporated into building materials and some examples of their typical activity concentrations are listed in Table 4 (Cliff et al, 1984). The type and range of materials for which data is presented would still represent contemporary building materials.

TABLE 4 Activity concentrations of some building materials

Material		Activity concentration, Bq g^{-1}	
Type	Main content	^{226}Ra	^{232}Th
SL20 Brick	Silica	0.0329	0.0148
F54 Brick	Flint	0.696	0.0516
Kirton brown brick	Clay	0.0842	0.0512
Fife-stone block	Granite	0.050	0.0547
Insulating block	Pulverised fuel ash	0.077	0.170
Exemption concentration, Bq g^{-1}		*10*	*10*

The data in Table 4 indicate that the activity concentrations of radionuclides in building materials are far below the exemption concentrations.

3.1.4 Potash, phosphate rock and fertilisers

Over one million tonnes of potash (95% potassium chloride) is mined in the UK each year, mainly for use in the fertiliser industry (Raffestin et al, 1998). The concentration of ^{40}K in potash is about 15 Bq g^{-1}, which is below the exemption concentration for ^{40}K of 100 Bq g^{-1}. Concentrations of other natural radionuclides are at least an order of magnitude below their respective exemption values (Raffestin et al, 1998).

Phosphate rock was until the early 1990s, imported and processed in the UK, but this has now ceased (RIFE, 2007). The typical activity concentration of ^{238}U in phosphate rock of sedimentary origin is about 1.5 Bq g^{-1} with some samples having concentrations up to 5 Bq g^{-1} (UN, 1982). This material is used to make agricultural fertilisers and some examples of the concentration of natural radionuclides in fertilisers are given in Table 5 (UN, 1982), with the relevant exemption concentration.

TABLE 5 Activity concentrations of phosphate fertiliser

Material	Activity concentration, Bq g^{-1}						
	^{238}U	^{230}Th	^{226}Ra	^{210}Pb	^{210}Po	^{232}Th	^{40}K
Superphosphate (USA)	0.74	0.67	0.79	-	-	0.02	-
Superphosphate (Belgium)	1.1	-	0.91	-	-	<0.025	<0.18
PK-Fertiliser	0.41	-	0.37	-	-	0.015	5.9
Triple superphosphate (USA)	2.1	1.8	0.78	-	-	0.048	-
Diammonium phosphate (USA)	2.3	2.4	0.21	-	-	0.015	-
Exemption concentration, Bq g^{-1}	*1*[1]	*1*	*10*	*10*	*10*	*1*[1]	*100*

1. Values for U(nat) and Th(nat).

The activity concentration of uranium in phosphate rock is at or slightly above the exemption concentration for natural uranium in secular equilibrium with its decay products. For samples of superphosphate and PK-Fertiliser, the uranium concentration is close to or below the exemption level for uranium in secular equilibrium with its decay products. For triple superphosphate and diammonium phosphate, which have higher uranium concentrations, the uranium is not in equilibrium with its decay products. In those materials the uranium concentration is below the exemption concentration for ^{238}U, which is 10 Bq g^{-1}. For all these materials the concentrations are below the levels at which the transport regulations would be applied.

3.1.5 Ores and mineral sands

There are a number of ores and minerals that are used in various industrial processes and some of these materials contain relatively high concentrations of natural radionuclides. Also, during these processes as a result of refining the substances being extracted, these radionuclides tend to be concentrated in the waste streams. Refractory bricks containing zircon are used for high temperature furnaces. These are manufactured from ores such as baddeleyite which also contains natural uranium and thorium. A few hundred tonnes of such bricks were estimated to be produced in the UK each year in a total of some 2000 tonnes of refractory material (Harvey et al, 1993). The concentration of natural radionuclides in ores and minerals shows a wide variation. However, there is now little or no use in the UK of the higher activity minerals. Some

examples of typical activity concentrations for a range of such minerals are given in Table 6 (Hipkin and Shaw, 1999).

TABLE 6 Typical activity concentrations of some ores

Ore	Main constituent	Activity concentration, Bq g^{-1}	
		^{232}Th[1]	^{238}U[1]
Ilmenite	Iron titanium oxide	1	2
Rutile	Titanium dioxide	0.2	0.2
Rare earth concentrate	Cerium oxide	5	0.1
Baddeleyite	Zirconium oxide	1	10
Zircon	Zirconium silicate	0.6	3
Pyrochlore	Niobium oxide	80	10
Monazite	Cerium phosphate	300	40
Exemption concentration of Th(nat) and U(nat), Bq g^{-1}		*1*	*1*

1. Assumed to be in secular equilibrium with its decay products

For each material, there is a range in activity concentrations and so for all the materials some samples are likely to be above the relevant exemption concentration. However, only pyrochlore and monazite will have concentrations that will also exceed the exemption values multiplied by the factor of 10, shown in Table 1, and so would be subject to the transport regulations. Other materials such as tantalite can also have relatively high concentrations of natural radionuclides. However, it is understood that there is currently no large scale import, processing, or use of these materials in the UK (Shaw, 2007). There were such industries in the UK some years ago but those operations have now ceased.

There are industries that import and process lower activity materials. The pigment titanium dioxide is extracted from Ilmenite and rutile, which may be transported in bulk by sea to a port and then carried in railway trucks. Zircon sand and flour is also used in a number of industries, for example for the production of refractory bricks, ceramic glazes and for high temperature casting. Zircon sand and flour is normally bagged during transport. In such materials, the activity concentrations may be slightly higher than the exemption concentrations of uranium and thorium, but do not exceed 10 times those values and therefore are outside the scope of the transport regulations.

For those materials that are outside the scope of the transport regulations a generic assessment was carried out to estimate the levels of potential radiation exposure of workers and members of the public during transport operations. Dose rates were calculated using Microshield (Negin, 1986) and the assumptions are described in Appendix A. The transport of zircon flour was used as an example and is taken as representative of a number of operations, including, for example, the transport of phosphate fertiliser. It was found that the highest annual dose to a driver is less 0.2 mSv, and the highest annual dose to a member of public would be less than a tenth of a microsievert.

3.2 Wastes from the oil, gas and china clay industries

3.2.1 Oil and gas industries

Offshore oil extraction from installations in the seas around the UK can result in the deposition of scales within pipework and other equipment. The scale arises from the deposition of insoluble compounds from the water used in the extraction process. The scale consists mainly of sulphates, such as barium sulphate, and carbonates, such as calcium carbonate. Naturally occurring radium (^{226}Ra and ^{228}Ra) from the rocks of the sea bed also precipitate mainly as radium sulphate within pipework and other components such as vessels, separators and valves used in the extraction process. There are no significant quantities of other members of the uranium and thorium decay chains present in the scale. The equipment is descaled or replaced at regular intervals and so there is no significant build up of ^{210}Pb and ^{210}Po. Much of the scale is removed and disposed of offshore, but equipment that cannot be descaled there is brought ashore to a descaling plant in Scotland. The scale waste is macerated, mixed with water, and discharged by pipeline to the sea, so that currently there is no transport of the waste offsite.

The quantity of scale removed annually from components at that facility has varied over recent years from about 30 tonnes to 70 tonnes, and is typically around 40 tonnes (Sniffer, 2004a). The quantity per component varies from 0.5 kg for small items to 5000 kg for the larger items. The items consigned from the platforms to the onshore descaling companies consists of pipes (known as “tubulars”) up to 14 m in length, and other components such as pumps valves and flexible hoses (Raffestin et al, 1998). The external surfaces of these components are descaled offshore and any apertures are sealed with covers and/or wrapped in e.g. polythene sheets to prevent any loss of the internal contamination. There is a further facility in the south of England but the operations there handle much lower quantities of waste. That facility receives equipment from an inland oil field that is contaminated with ^{210}Pb and ^{210}Po. This operation results in approximately one drum of waste a month which is disposed of at a radioactive waste repository (Sniffer, 2004b).

Examples of the activity concentrations of radium, which are very variable, are given in Table 7 (Raffestin et al, 1998; Sniffer, 2004a, Ghose and Heaton, 2005). Concentrations of ^{226}Ra can range up to a few thousand Bq g^{-1} however such high values are rare. Concentrations of ^{226}Ra are typically around 40 Bq g^{-1} or less (Ghose and Heaton, 2005). Some data on the activity concentration distribution in a sample of tubulars showed that some 90% of values were less than 50 Bq g^{-1}, and about half were less than 10 Bq g^{-1} (Sniffer, 2004a). Although most of the contaminated items have activity concentrations below the exemption value, the range is large, so that the transport of many of these items are subject to the transport regulations, taking into account the multiplication factor of 10 with the relevant exemption value. In practice, almost all such items are consigned as surface contaminated objects (SCO-I). There were 340 consignments during 2007, only 4 being transported as excepted packages. The external surface dose rates close to these items are very low. A calculation based on a radium activity concentration of 40 Bq g^{-1} indicated a low external surface dose rate of about 3 µSv h^{-1}. Using conservative assumptions, the calculations set out in Appendix A predict maximum annual doses to transport workers of less than 0.1 mSv. This is

consistent with experience as personal monitoring data for workers involved in transporting these items to the descaling plant indicate that they do not receive any measurable annual doses. The calculations were extended to estimate the potential dose to any member of the public from such consignments, using some simple assumptions described in Appendix A. The calculations indicated that the maximum annual dose would be much less than 1 µSv.

TABLE 7 Activity concentrations of oil and gas scales

	Scale type			
	Oil		Gas	
	^{226}Ra	^{228}Ra	^{210}Pb	^{210}Po
Average activity concentration[1], Bq g^{-1}	15 – 25	10 – 20	-	-
Average activity concentration[2], Bq g^{-1}	40	-	-	-
Average activity concentration[3], Bq g^{-1}	-	-	10	10
Activity concentration range[1], Bq g^{-1}	0.37-2000	0.1-2000	1-2000	1-600

1. Raffestin et al, 1998; 2. Ghose and Heaton, 2005; 3. Rounded values from Sniffer, 2004a

Natural gas from the gas fields around the UK contains radon (^{222}Rn) which gives rise to the decay products ^{210}Pb and ^{210}Po. These radionuclides deposit on the equipment used to process the natural gas, and liquid natural gas, as thin coatings or “black sludges”. Activity concentrations are very variable and can range up to a few thousand Bq g^{-1}, as indicated in Table 7 (Raffestin et al, 1998). The transport of some of these wastes is therefore subject to the transport regulations, but it is understood from the limited data available (Sniffer, 2004a; Sniffer, 2004b) that the volume of such waste transported in the UK is low. Since ^{210}Po is an alpha emitter and ^{210}Pb a weak gamma emitter, external dose rates are extremely low. A calculation, described in Appendix A, indicates that the dose rate on the surface of a drum containing this waste would be about 0.1 µSv h^{-1}, and therefore doses to workers transporting this waste would be negligible.

3.2.2 China clay industry

The granite rocks of Cornwall, and other parts of south west England, are noted for their elevated concentrations of uranium and thorium. The weathering of the feldspar component of granite results in the formation of kaolinite. This is extracted from a number of sites in Cornwall for the production of china clay which has many applications, from the production of porcelain and paper manufacture to inclusion in medicinal products. The raw material contains uranium and thorium and their decay products which are approximately in secular equilibrium. The extraction and refining of the china clay involves the use of different types of equipment such as metal pipes, centrifuges, dryers, pumps and other components. During the refining process sodium hydroxide and sulphuric acid are used to improve the properties of the china clay, and this also creates conditions which result in the release of barium and subsequent precipitation of barium sulphate scale. Radium, having similar chemical properties to barium is also found in the scale. The only other radionuclides found in the scale are ^{210}Pb and ^{210}Po, which are due to ingrowth from ^{226}Ra. The scale deposits within the equipment tend be in very thin irregular layers especially at junctions or bends in pipes.

The existence of the scale was first recognised in 1996 and since then a purpose-built facility has been developed to remove scale from used equipment so that the metal can be recycled, or reused, and the waste scale can be managed and disposed of appropriately (Read et al, 2004). There are some nine sites in the area surrounding the facility from which contaminated equipment is sent for decontamination. A visit was made to the facility to gather data for this study, and dose rate measurements were made to estimate radiation doses from the transport operations. Surface dose rates on the items, recorded by the company, vary from a few μSv h^{-1} to about 200 μSv h^{-1}. Data recorded by the company for a sample of pipes in a few consignments showed that the maximum surface dose rates of most pipes are in the range 10 to 50 μSv h^{-1}. During the visit measurements were made around pipes which had surface dose rates in this range (Appendix A.3). In each consignment there are some 10 to 20 items which are transported as surface contaminated objects (SCO-I). These are wrapped in polythene sheets to prevent any loss of the internal contamination during transport. During 2007 there were 80 such consignments. These shipments include a journey of up about an hour and in addition the drivers may be involved in loading and unloading the consignments. The drivers are also involved in the general work at the decontamination site. The items are unloaded and stored inside freight containers at the site. A calculation, described in Appendix A, indicates that the annual dose to a driver from transporting these items to the decontamination site is less than 0.1 mSv. This is consistent with experience of personal dosimetry records, as these workers typically receive a maximum annual dose of 0.1 mSv to 0.2 mSv from operations at the facility, and from driving the consignments. Assumptions about the potential exposure of individual members of the public, described in Appendix A, indicate annual doses of less than 1 μSv.

The facility includes a preparation area where the items are cut up or dismantled into convenient lengths. Ultra high pressure water jetting is used to remove the scale. This water and the suspended solids are run off into a settling tank, from which water is extracted, filtered and reused in the process. A measured quantity of the remaining slurry is mixed with cement and placed in steel 200 litre drums, and then allowed to cure in a storage area. Much research and development work was carried out to ensure that the formulation of this material results in a solid matrix which immobilises the waste to a standard suitable for disposal. Each batch of cement matrix is tested for its radionuclide content before being sent for disposal. Results for three typical batches were supplied by the company and are presented in Table 8.

TABLE 8 Radionuclide concentrations in cemented waste

Sample	Activity concentration, Bq g^{-1}							
	^{226}Ra	^{210}Pb	^{210}Po	^{228}Ra	^{228}Th	^{238}U	^{234}U	^{232}Th
A	1.369	0.231	0.229	0.237	0.237	0.033	0.039	0.039
B	1.115	0.204	0.200	0.437	0.423	0.042	0.063	0.043
C	1.253	0.200	0.199	0.375	0.370	0.047	0.059	0.063
Exemption concentration, Bq g^{-1}	*10*	*10*	*10*	*10*	*1*	*10*	*100*	*10*

In all cases the radionuclide concentrations are well below the relevant exemption value, and so the material is exempt from the transport regulations. The drums are loaded into

a skip that is used to take them to a landfill site for disposal. In recent years two consignments of 55 drums each have been taken each year for disposal. Measured dose rates around a typical skip, and information on the frequency and duration of these shipments, described in Appendix A, indicates that the driver would receive an annual dose of less than 3 μSv from loading, unloading and transporting these drums. The dose rate at a few metres from the skip indicated that their movement to the disposal site would result in annual doses to members of the public of much less than 1 μSv.

4 SUMMARY

This study considered the transport of NORM which are not intended to be used for the extraction of radionuclides and therefore did not cover the transport of uranium ores by the nuclear industry. From the information currently available the most significant movements of NORM in the UK are items contaminated with scales associated with the oil and china clay industries. It was found that the annual dose to the most exposed transport workers from those shipments was very low, at less than 0.1 mSv. These materials are transported within the normal application of the transport regulations, almost all as surface contaminated objects (SCO-I).

In some countries there are significant movements of natural materials with high levels of natural radionuclides, for example in mining or mineral processing industries. Within the UK there were some industries that processed such materials some years ago but these have either closed or transferred to other countries. During the course of this study no evidence was found of large scale transport of minerals and ores which have an activity concentration high enough to require the application of the transport regulations. Materials with lower activity concentrations are transported in the UK. These have activity concentrations of uranium and thorium close to or slightly greater than the exemption concentrations but not high enough to come within the scope of the transport regulations. For these materials a generic assessment was carried out using the example of the transport of zircon flour, which indicated that the annual doses to transport workers would be less than 0.2 mSv. Similar generic assessments show that the annual dose to any member of the public from the shipment of each type of NORM would be much less than a microsievert.

5 CONCLUSIONS

The most significant movements of NORM in the UK are items contaminated with scales associated with the oil and china clay industries, which are transported within the normal application of the transport regulations. These shipments result in very low doses to transport workers. Materials with low activity concentrations, and which are therefore outside the scope of the transport regulations, are transported in the UK and assessments show that the radiological consequences of these movements are also

very low. Assessments of the probable radiological impact on members of the public from the transport of each type of NORM show that individual doses are extremely low.

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7 GLOSSARY

Term	Description
A_2 value	The maximum activity, in TBq, of a radionuclide that can be transported within a Type A package, for material in a potentially dispersible form. Multiples of A_2 are used to specify a number of limits within the transport regulations.
Absorbed Dose	Measured in Grays (Gy), it is the amount of energy absorbed per kilogram of matter, for example tissue, as a result of exposure to ionising radiation.
Activity	The number of radioactive decays per unit time in a given material. Normally measured in disintegrations per second (Bq). Since this is a very small unit activities of materials may be expressed in multiples of Bq, e.g. TBq (10^{12} Bq).
Alpha emitter	A radionuclide that decays emitting an alpha particle.
Alpha particle	A particle emitted by a radionuclide consisting of two protons and two neutrons (i.e. the nucleus of a helium atom).
Beta emitter	A radionuclide that decays emitting a beta particle.
Beta particle	An electron or positron emitted by a radionuclide.
Effective Dose	Measured in Sieverts (Sv), it is a measure of the overall exposure of an individual from ionising radiation. It is dependent on the absorbed dose, type of radiation and regions of the body affected. Since the Sievert is a large unit, doses are more commonly expressed in millisieverts (mSv) or microsieverts (µSv). A mSv is one thousandth of a Sv and a µSv is one millionth of a Sv.
Effective dose rate (or "Dose rate")	The rate at which effective dose from external radiation is received, measured in units of Sv h^{-1}, mSv h^{-1}, or µSv h^{-1}
Ionising Radiation	Radiation capable of breaking chemical bonds, causing ionisation and damage to biological tissue.
Low toxicity alpha emitters	Natural uranium, depleted uranium, natural thorium, ^{235}U, ^{238}U, ^{232}Th, ^{228}Th and ^{230}Th when contained in ores or physical and chemical concentrates; or alpha emitters with a half-life of less than 10 days.
Nuclide	A species of atom characterised by a nucleus with a specific number of protons and neutrons.
Package	There are five main types of packages used to carry radioactive material: • Industrial Packages are industrial containers, such as drums, used to carry bulky low activity materials, or contaminated items. • Excepted packages are simple packages used to carry low activity materials and sources. They are mainly used to transport low activity diagnostic test materials to hospitals. • Type A packages are used to transport medium activity material such as medical or industrial isotopes. They must withstand normal conditions of transport including minor mishaps. • Type B packages are used to transport high activity sources and materials, such as Irradiated Nuclear Fuel (INF). They provide shielding from high radiation levels even under extreme circumstances. They must meet severe mechanical and thermal test requirements, which simulate accident conditions. • Type C packages are for the transport by air of greater quantities of radioactive material than is allowed to be transported by air in Type B packages. They must be designed to withstand very serious accidents such as aircraft crashes.
Radionuclide	A nuclide which spontaneously loses energy or disintegrates into another nuclide, resulting in the emission of ionising radiation.

APPENDIX A

Estimates of exposures of workers and members of the public

In this appendix very approximate estimates are made of the radiation exposures that may result from the transport of NORM in the UK. Dose rates from the materials were calculated using Microshield (Negin, 1986). In the case of equipment contaminated with china clay scale, dose rate measurements were made during a visit to a decontamination facility, which were also used to estimate annual doses. In order to estimate the radiation exposures of workers and members of the public a number of assumptions must be made on exposure times, frequency of movements and dose rates from consignments. The exposure conditions used and assumptions made here are deliberately very simple as a complex model would be unjustified, owing to the variability and uncertainty of those parameters. Because the parameters are so uncertain, only individual doses were calculated. These uncertainties made any estimate of collective dose unreliable and therefore no attempt was made to make those estimates.

A1 MATERIAL OUTSIDE THE SCOPE OF THE REGULATIONS

Sections 3.1.4 and 3.1.5 describe the transport of materials which have radionuclide concentrations around or slightly above the exemption concentration values, but would not have concentrations a factor of 10 above those values. When carried in large quantities they would therefore meet the definition of radioactive material but would not come within the scope of the transport regulations.

To illustrate the likely level of radiation exposures of workers and members of the public from the transport of such materials an example is used of the transport of zircon flour. It is assumed that this material is carried in sacks on a truck in a load of 20 tonnes. The annual dose received by the driver was calculated using a very conservative annual driving time (with a full load) of 600 h.

It was assumed that the parent radionuclides are in secular equilibrium with their decay products. The activity concentrations of ^{232}Th and ^{238}U are typical values (Hipkin and Shaw, 1999). The activity concentration of ^{235}U is obtained from the natural ratio of the concentration of ^{235}U to ^{238}U. The other main assumptions are included in Table A1.

The dose rate in the driver's cab was calculated to be approximately 0.3 µSv h^{-1}, which would give an annual dose of 0.18 mSv. A member of the public was assumed to be exposed near a truck for about 1 minute per week, that is, an annual exposure time of about 1 hour. The dose rate at 5 m from the side of the truck was calculated to be 0.04 µSv h^{-1}, which would give an annual dose of 0.04 µSv.

TABLE A1 Values used in the assessment of zircon flour transport

Factor	Value
Activity concentrations, Bq g^{-1}:	
^{232}Th	0.6
^{238}U	3.0
^{235}U	0.15
Load dimensions, m:	
Height	1.5
Width	2.0
Length	4.0
Shielding (steel), m	0.01
Load to driver distance, m	1.0
Annual driving time, h	600
Distance to member of the public, m	5.0
Annual exposure time of member of the public, h	1.0

A2 EQUIPMENT CONTAMINATED WITH OILFIELD SCALE

Section 3.2.1 describes the transport of oil extraction equipment contaminated with scale containing ^{226}Ra and ^{228}Ra. Much of this scale is removed offshore and the scale remaining in the equipment typically contains about 40 Bq g^{-1} of ^{226}Ra (Ghose and Heaton, 2005). Data from a large sample of almost 900 tubulars and other equipment showed that approximately 80% had radium concentrations less than this value (Sniffer, 2004a). Data on the ^{228}Ra content is sparse and the activity concentration ratio of ^{226}Ra to ^{228}Ra probably varies between oilfields, depending on the rock type. However one report (Sniffer, 2004a) indicates a concentration some 20% lower than ^{226}Ra, and therefore it is assumed here that the ^{228}Ra concentration is about 30 Bq g^{-1}. The other main assumptions are included in Table A2.

The dose rate at the surface of a single pipe was calculated to be 3.2 µSv h^{-1}, so that exposures to loaders and drivers would be expected to be low. For a consignment of 20 2 m long pipes the dose rate in the driver's cab was calculated to be 0.07 µSv h^{-1}. Using a very conservative annual driving time of 600 h, this would give rise to an annual dose of about 40 µSv. This is consistent with the fact that these workers receive no measurable doses; that is less than 0.1 mSv y^{-1}. The dose rate at 5 m from such a consignment was calculated to be 0.008 µSv h^{-1}. Assuming a member of the public is exposed to such a vehicle for about 1 minute a week, that is about 1 h y^{-1}, this would result in an annual dose of 0.008 µSv.

TABLE A2 Values used in the assessment of transport equipment contaminated with oilfield scale

Factor	Value
Single pipe dimensions, m:	
Diameter	0.15
Length	2.0
Pipe thickness	0.01
Scale thickness	0.01
Load dimensions, m, for 20 pipes:	
Height	0.15
Width	2.0
Length (two sets of 2m long pipes)	2.0
Shielding (steel), m	0.01
Load to driver distance, m	1.0
Annual driving time, h	600
Distance to member of the public, m	5.0
Annual exposure time of member of the public, h	1.0

A3 EQUIPMENT CONTAMINATED WITH CHINA CLAY SCALE

During a visit to the decontamination facility dose rate measurements were made around a freight container in which some 3 truck loads of pipes were being stored. The rounded values of the measured dose rates are given in Table A3.

TABLE A3 Measured dose rates from pipes contaminated with china clay scale

Position	Distance, m	Dose rate, μSv h^{-1}
Side of container	Surface	2
	1	2
	2	1
End of container with doors open, i.e. no shielding (assumed closest position of driver in truck cab)	1	3

The measurement made at the assumed position of the driver was 3 μSv h^{-1} from three loads, and therefore the dose rate in a driver's cab while transporting a typical load of such pipes would be approximately 1 μSv h^{-1}. With 80 journeys a year, each taking about 1 hour, this would result in an annual dose of 80 μSv. This is consistent with dosimetry results for these workers who typically receive a maximum of 0.2 mSv y^{-1} from operations at the facility, and driving the consignments. The measurements further indicated that the dose rate at 5 m from the side of a typical consignment is in the order of 0.1 μSv h^{-1}. Assuming a member of the public is exposed to such a vehicle for about 1 minute a week, that is about 1 h y^{-1}, this would result in an annual dose of about 0.1 μSv.

Drums containing cemented waste are carried to a disposal site in a skip, which is loaded onto a truck. The dose rate at the surface of the skip is typically 1.5 µSv h^{-1} and about 0.3 µSv h^{-1} at 2 m. At the position of the driver during the shipment the dose rate is about 0.1 µSv h^{-1}. Two loads of 55 drums are currently transported annually. Assuming a loading and unloading time of some 4 hours and a driving time of 1.5 hours, the annual dose to such a driver would be less than 3 µSv, from these disposal shipments. Also, the dose rates at a few metres from the skip are very low and their movement to the disposal site would result in annual doses to members of the public of much less than1 µSv.

A4 WASTE FROM NATURAL GAS PRODUCTION

Natural gas is brought to the UK from installations in the North Sea and other coastal areas by pipeline. Radon in the natural gas decays to ^{210}Pb, ^{210}Bi and ^{210}Po which can be deposited on the inner surfaces of pipes and other equipment within a mixture of scale deposits, corrosion products and other non-radioactive solids, forming a black sludge. Information on the volume collected and disposed of in the UK is very limited but it is probably very low (Sniffer, 2004a). Data on the radionuclide concentration of this material indicates that typical activity concentrations are in the order of 10 Bq g^{-1}, but can range up to a few thousand Bq g^{-1}. One operator reported results for one gas/ condensate separator: 10.1 Bq g^{-1} of ^{210}Pb, 6.49 Bq g^{-1} of ^{210}Po and 0.15 Bq g^{-1} of total radium (Sniffer, 2004a). Similar wastes arise from pipeline pigging operations.

Calculations were carried out using activity concentrations of 10 Bq g^{-1} for ^{210}Pb and ^{210}Po, and 0.2 Bq g^{-1} for both ^{226}Ra and ^{228}Ra. The dose rate at the surface of a 200 litre drum filled with such sludge was calculated to be about 0.1 µSv h^{-1}. Doses to workers handling and disposing of these drums would be negligible.

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