THE RADIOLOGICAL IMPACT OF THE STEEL PRODUCTION INDUSTRY IN THE UK

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1 ABSTRACT

As part of its periodic review of radiation doses to the population of the United Kingdom, the National Radiological Protection Board identified the need to estimate the radiological impact of the operation of non-nuclear industries which use or produce materials containing enhanced levels of naturally occurring radionuclides. The steel production industry has been assessed as part of this study. The impact of the primary industry, the waste streams produced and the use of by-products have been considered. A number of potential exposure scenarios were assessed: the exposure of members of the public to atmospheric releases from the steel production site, the disposal of steel industry waste in landfill and the use of slag in building materials, the exposure of workers at the steel plants and landfill sites, and the exposure of workers who manufacture building materials containing slag. The predicted peak individual doses to typical members of the hypothetical critical group from atmospheric releases via the stack are approximately 90 μSv y^{-1} to infants, 60 μSv y^{-1} to children and 40 μSv y^{-1} to adults. Predicted doses to 'average' individuals living in the local area are less than 2 μSv y^{-1} for all age groups. The maximum predicted doses to workers at the steel production plant, landfill workers, and workers manufacturing building materials containing slag are, respectively, approximately 80 μSv y^{-1}, 10.5 μSv y^{-1} and 2 μSv y^{-1}. The predicted radon concentration in buildings constructed from materials containing slag is 11 Bq m^{-3}. The predicted dose from inhalation of radon is about 600 μSv y^{-1} and the predicted external dose to an individual living in a home constructed from building materials containing slag is about 800 μSv y^{-1}. The predicted peak individual risk from landfill disposal of steel industry waste is 5.2 10^{-9} y^{-1}.

Under UK legislation the radiological controls on the operation of steel production sites are confined to atmospheric releases from the stacks. There are no restrictions on the disposal of solid wastes or the use of by-products, which relate to their radionuclide content. This position is entirely consistent with the low radiological impact of the industry as presented here. The lack of regulation is also consistent with developing EC guidance in this area. The only exception to this is the use of slag in building materials, where EC guidance indicates that future restrictions may be required.

2 INTRODUCTION

The raw materials used in steel production are iron ore, coal and limestone. The naturally occurring radionuclides present in these raw materials are potassium-40 and those in the uranium-238, uranium-235 and thorium-232 decay chains. The steel production process results in releases to the environment of materials containing enhanced concentrations of naturally occurring radionuclides, relative to the raw materials used. A study has been undertaken to assess the radiological impact of steel production in the UK (1). The radiological impact of releases to atmosphere, disposal of waste and the use of by products from the steel production process have all been considered.

In the UK, the Radioactive Substances Act 1993 (RSA93) (2) regulates the accumulation, storage and disposal of radioactive waste, principally to control doses to members of the public. Materials which have concentrations of naturally occurring radionuclides (other than those involved in the nuclear fuel cycle) lower than the values given in Schedule 1 of the RSA93 are not considered to be radioactive and are therefore excluded from the provisions of the Act. The concentrations of lead-210 and polonium-210 in some of the gases emitted to atmosphere during steel production exceed the limits for exclusion given in Schedule 1. These atmospheric releases are therefore subject to regulatory control and are authorised by the Environment Agency.

3 THE STEEL PRODUCTION PROCESS

Until recently, the Corus group operated four integrated steel production plants in the UK. In June 2001 one of these plants stopped producing steel and will soon be closed. These are the only sites in the UK producing steel from iron ore; all the other steel production plants in the UK produce steel by recycling scrap metal. Since radionuclides are released from the raw materials during initial processing of the iron ore and in the production of iron, the steel that is produced contains extremely low levels of radioactivity. It was therefore considered unnecessary to assess the steel works producing steel from recycled scrap metal.

The steel making process consists of three stages. Two of these stages are of concern regarding the enhancement of naturally occurring radionuclides, these are sintering and iron making. Sintering is the preparation of iron ore and coal into an iron rich clinker suitable for addition to the blast furnace. Sintering is an important part of the overall process; it reduces waste and provides an efficient raw material for iron making in the blast furnace. In the blast furnace, the iron in the iron ore and sinter is melted out to form a pool of molten metal in the bottom of the furnace and the limestone combines with impurities forming a liquid slag, which floats on top of the metal. The third stage, conversion of iron into steel in the basic oxygen (BOS) furnace, also produces off-gas dust and slag, but the sintering and blast furnace processes together remove nearly all the naturally occurring radioactivity from the iron, so the radioactivity in releases from the conversion process is unlikely to be significant. The off-gases from all three processes are cleaned and then recycled, with only a very small fraction of dust escaping to the atmosphere. The waste from the cleaning systems is stored in lagoons before final disposal to landfill. The slag from the blast furnace and steel-making processes is generally sold to companies who recycle the slag for use in road construction and maintenance or in housing construction.

4 SOURCE TERMS

The raw materials for steel production originate from several different countries and the initial activity concentration in each of the materials is very low. During the stages of steel production, the concentrations of radionuclides are enhanced to differing extents. Information on the quantities of waste generated at a steel production site, the proportions released to atmosphere and disposed to landfill, and the radionuclide content of the different waste streams was provided by Corus (3). Total quantities of waste released to atmosphere and disposed to landfill from all steel production plant in the UK were obtained from the Environment Agency (4). Finally, information on the radionuclide content of slag, the quantities produced and sold and its applications were obtained from various sources including Corus (3) and the companies that buy the slag (5). The quantities of wastes and by products that are released, disposed and re-used were combined with information on radionuclide content to produce a source term to use in the assessment of the radiological impact of the steel production industry in the UK. Table 1 gives a summary of the source term data used in this study to evaluate individual doses and risks.

Table 1: Source term data used in the study

	Activity concentration Bq kg^{-1}			Quantitiy kg y^{-1}	Total activity Bq y^{-1}		
Atmospheric release	^{210}Pb	^{210}Po			^{210}Pb	^{210}Po	
	1.0 10^{4}	6.5 10^{3}		6.2 10^{5}	6.2 10^{9}	4.0 10^{9}	
Landfill disposal	^{210}Pb	^{210}Po			^{210}Pb	^{210}Po	
	9.0 10^{2}	2.9 10^{2}		5.7 10^{7}	5.1 10^{10}	1.6 10^{10}	
Slag use	^{238}U	^{232}Th	^{235}U		^{238}U	^{232}Th	^{235}U
	8.8 10^{1}	4.9 10^{1}	4.0 10^{0}	1.6 10^{9}	1.4 10^{11}	7.8 10^{10}	6.4 10^{9}

5 METHODOLOGY

5.1 Atmospheric releases

Two exposed groups were considered: a group intended to represent the average exposure of local people, and a group representative of people who are assumed to be located at a place, and have habits such that they are likely to receive the highest dose from the plant (hypothetical critical group). For the average group it was assumed that the individual lives 5 km downwind of the stack, and remains at that location for the entire year. The assumptions used to characterise a typical individual from the hypothetical critical group were based on those described in reference 6. It is assumed that they live on a farm 500 m from the stack and they spend all their time at the location. Doses to adults, children and infants were determined. It should be stressed that the assumptions made for the two groups are not site specific but are generic assumptions applicable to the UK. The predicted doses will therefore differ from those that would be determined using site-specific information on locations of habitation and agricultural practices around a site. Given the conservative nature of the assumptions made in this study it is likely that the predicted doses from a site-specific study would be lower than those presented herein.

Radionuclides are discharged into the environment via the stack of the sinter plant and the blast furnace. The heights of the stacks at the Corus sites in the UK are between 76m and 133m (7). An effective release height of 100m was assumed for a typical steel works. Individual doses and risks from atmospheric releases from the stack were assumed to result from five exposure pathways: inhalation of radionuclides in the plume, external irradiation by radionuclides in the plume, inhalation of radionuclides resuspended from a surface deposit, external irradiation by deposited radionuclides, and ingestion of food grown on land contaminated by a deposit of radionuclides.

To assess doses from these pathways, the radionuclide concentrations in air, deposition rates and external doses from gamma irradiation from the cloud were calculated. This was done using the atmospheric dispersion model PLUME (part of the PC CREAM (8) suite of models). Integrated dose rates per unit deposit were calculated for inhalation of resuspended radionuclides, external irradiation and ingestion of food using parts of the PC CREAM suite of models: RESUS, GRANIS, and the NRPB terrestrial food chain model FARMLAND (9). A full description of the dose calculations and the assumptions made is given in reference 1.

5.2 Landfill disposal

The majority of dust disposed to landfill originates from the blast furnace and BOS furnace gas cleaning systems. The activity concentrations of lead-210 and polonium-210 in the collected dust are measured before disposal to landfill. The total quantity of waste disposed to landfill from a single site (in 1999), the measured activity concentrations and the total activity disposed are presented in Table 1. These values were used to determine the individual doses and risks resulting from one year's disposal inventory.

Following the disposal of radioactive material there are two main scenarios in which exposure to people could occur. The most likely occurrence (migration scenario) is the gradual migration of radionuclides with ground water from the waste through the surrounding rock and soil (geosphere) into the local environment (biosphere). From here, people could be exposed by a wide variety of routes including direct external irradiation from contaminated soil and the consumption of contaminated food. This type of exposure has a probability of occurrence close to unity. The second way (probabilistic scenarios) involves events that disturb the natural evolution of the site, and has a lower probability of occurrence. One example is excavation of the site for development. This study considered the following scenarios for exposure of members of the public: migration, borehole water extraction, excavation during development of the site, and residence on the site. Doses to landfill workers were also determined. For the study, modelling of the migration of radionuclides in the geosphere was performed using GEOS (10) and transfer in the biosphere using BIOS (11); both models were developed at NRPB.

5.3 Production and use of construction materials containing slag

All slag that is produced during steel production is sold and recycled. The integrated steel production plants run by Corus currently give sole rights to all of their slag arisings to Tarmac (3). The main areas of use for this slag are in road construction and maintenance, and housing construction. It is used for example, in the manufacture of bricks, cement, concrete and insulating materials. This paper will only discuss the radiological impact on workers manufacturing building materials containing slag and members of the public living in houses constructed from materials containing slag. The impact of the use of slag in various other scenarios is evaluated and discussed in reference 1.

Methodologies, assumptions and data used in the determination of doses to workers involved in the manufacture of building materials containing slag were developed for this study using information from previous, similar assessments of occupational exposures and information obtained from industry (5). Doses to individuals living in homes constructed from materials containing slag, from the inhalation of radon originating from radium in the building materials were estimated using a standard approach (12). Doses from external irradiation were determined using an EC developed methodology (13, 14).

The quantity of slag used in cement and concrete is usually up to 35%, but can be as much as 55%. The proportions of ordinary Portland cement and granulated blast furnace slag are varied to achieve products complying with BS 146 (15) or BS 4246 (16). For this study it has been assumed that cement and concrete contain 35% blast furnace slag. It is important to consider that building materials other than those containing slag also contain naturally occurring radionuclides, which will result in exposures of workers and members of the public. Similarly, it should be remembered that slag replaces other constituents that would themselves contain naturally occurring radionuclides and thus give rise to radiation exposures. In order to build up a picture of the overall radiological significance of the use of slag in building materials, several sets of doses have been produced. Sets of doses considering the impact of all the radionuclides present in the building materials (i.e. not simply those originating in the slag) have been estimated. The impact of the use of similar building materials that do not contain slag has also been assessed. A detailed description of the methodology, assumptions and data used to estimate doses from these pathways is given in reference 1.

5.4 Steel production plant workers

There are various areas at steel works where exposure to radionuclides from processed materials could occur. Clearly the doses received by individual workers will vary substantially depending in detail on their work activities, with the majority receiving trivial doses. The aim of this part of the study was to determine doses typical of those received by the most exposed workers. Workers at the blast furnace, exposed to cooling slag and dust containing enhanced levels of naturally occurring radionuclides, have been considered, as well as workers at the lagoons containing dust from the wet gas cleaning system and workers involved in the transferral of slag from production to storage areas. Each of these groups has been considered separately because the size of a steel production site means that it is unlikely that workers would be exposed in more than one area of the site. It is also known (3) that steel production workers have specific jobs and are unlikely to spend a significant amount of time in more than one area of the site. The three groups of workers are assumed to be exposed via four main pathways: external exposure, inhalation of dust in the workplace, inadvertent ingestion of dust and external irradiation from contamination of exposed areas of skin. Methodologies, assumptions and data used in the determination of doses to workers were developed for this study using information from previous, similar assessments of occupational exposures and information obtained from Corus (3).

6 RESULTS

The predicted individual doses and risks from all of the exposure scenarios discussed in the previous sections are presented in Tables 2 and 3. The predicted peak individual doses to typical members of the hypothetical critical group from atmospheric releases via the stack are approximately 90 μSv y^{-1} to infants, 60 μSv y^{-1} to children and 40 μSv y^{-1} to adults. Predicted doses to 'average' individuals living in the local area are less than 2 μSv y^{-1} for all age groups. The predicted peak individual risk from landfill disposal is 5.2 10^{-9} y^{-1}. This is from the probabilistic scenario of residence on the redeveloped landfill site. The maximum predicted dose to landfill workers is 10.5 μSv y^{-1}. The maximum predicted doses to workers at the steel plant, at the blast furnace, storage lagoons and slag heaps are, respectively, approximately 80 μSv y^{-1}, 3 μSv y^{-1} and 6 μSv y^{-1}. Doses from the scenarios involving the use of slag in building materials are presented in Table 3. A number of sets of doses are presented: doses from all radionuclides in the building materials containing slag; doses from radionuclides in similar building materials that do not contain slag; and the additional dose due to the use of slag as a component in the building materials. The second set of doses were estimated by making reasonable assumptions about the concentrations of naturally occurring radionuclides in the general constituents of building materials in the UK (13). These three doses allow the overall impact of the use of slag to be evaluated. It is important to note that the assumed concentrations of radionuclides in building materials were based on those for modern composite building materials. The results are clearly dependent upon the assumptions made regarding concentrations of activity in building materials, which can vary significantly, and the use of a 35% slag content. Nevertheless, they serve to provide a useful overall indication of the radiological impact of using slag in building materials. The total additional dose to an individual living in a house constructed with 35% slag is about 80 $\mu Sv\ y^{-1}$. The total additional dose to a worker manufacturing building materials with a 35% slag content is 2 $\mu Sv\ y^{-1}$.

Table 2: Peak annual individual doses and risks

Exposure scenario	Exposed group	Peak individual effective dose $\mu Sv\ y^{-1}$	Peak individual risk y^{-1}
Atmospheric release	Critical Adult	$4.3\ 10^{1}$	
	Critical child	$6.0\ 10^{1}$	
	Critical infant	$8.8\ 10^{1}$	
	Average adult	1.2	
	Average child	1.6	
	Average infant	1.8	
Landfill disposal	Public	$1.4\ 10^{2}$	$5.2\ 10^{-9}$
	Worker	$1.1\ 10^{1}$	$6.3\ 10^{-7}$
Steel worker	Blast furnace	$8.4\ 10^{1}$	
	Lagoon	2.8	
	Slag heap	5.7	

Table 3: Peak annual individual doses from building materials

Component	Individual dose μSv y^{-1}			
	Manufacturer	Resident Radon inhalation	Resident external	Resident Total
Building materials containing slag	$1.5\ 10^{1}$	$5.6\ 10^{2}$	$7.9\ 10^{2}$	$1.4\ 10^{3}$
Ordinary building materials	$1.3\ 10^{1}$	$5.1\ 10^{2}$	$7.6\ 10^{2}$	$1.3\ 10^{2}$
Additional dose from use of slag	1.7	$4.9\ 10^{1}$	$3.2\ 10^{1}$	$8.1\ 10^{1}$

7 SUMMARY AND CONCLUSIONS

The predicted doses to members of the public in the hypothetical critical group from stack releases are approximately 40, 60 and 90 μSv y^{-1}, to adults, children and infants, respectively. These doses have been calculated using cautious, generic assumptions and are not site specific. The stack releases from the actual sites are authorised by the Environment Agency under RSA93 and, at the time of authorisation, site specific environmental impact assessments were undertaken for each of the sites (7, 17). Reference 7 presents doses to members of the public from unit releases of activity from the stack; if these doses are scaled for the activity releases assumed for this study, the highest predicted dose to the most exposed individuals would be 6 μSv y^{-1} to infants. Reference 17 also presents site specific doses to the most exposed individuals from a particular steel production plant, and gives a value of 1.9 μSv y^{-1}. The IAEA has concluded (18) that a level of dose of some tens of microsieverts a year could reasonably be regarded as trivial by regulatory authorities. The site specific results indicate that the doses likely to be incurred by the most exposed individuals from stack releases are at a level that can be regarded as trivial.

The predicted doses to steel workers, landfill workers, and workers manufacturing building materials containing slag are in the range of a few to a few tens of μSv y^{-1}, with the exception of workers at the blast furnace where the predicted dose is about 80 μSv y^{-1}. It should be noted that doses to workers were assessed using very conservative assumptions, in particular the activity concentration in dust likely to be encountered at the blast furnace. All of the doses are significantly lower than 1 mSv y^{-1}, which EC guidance indicates is the dose level below which regulation is not necessary for workplaces processing materials with enhanced levels of naturally occurring radionuclides(19).

In the UK the acceptability of purpose built disposal facilities for radioactive waste would be judged against a risk target of 10^{-6} y^{-1} (20). This criterion relates to purpose built repositories for radioactive waste, and therefore does not necessarily apply to burial at landfill sites. However, risks below 10^{-6} y^{-1} are considered to be 'broadly acceptable' (21, 22), and this therefore seems a reasonable choice of criterion for judging such disposals. On this basis the peak risk to members of the public from the disposal of dust from cleaning systems in landfill sites conforms to this criterion.

The predicted radon concentration in buildings constructed from materials containing recycled slag is 10.8 Bq m^{-3} (4.4 Bq m^{-3} from radionuclides within the slag). This level satisfies EC guidance that the amount of radium in building materials should be restricted at least to a level where it is unlikely that it would be a major cause for exceeding the design level for indoor radon introduced in the Commission Recommendations (200 Bq m^{-3}) (14). The total external dose from building materials containing slag is about 800 μSv y^{-1}, giving a net dose of about 500 μSv y^{-1} when the outdoor external background is subtracted. This is within the range of 0.3 mSv y^{-1} to 1 mSv y^{-1} (excess external irradiation dose to that received outdoors) within which EC guidance indicates that controls on the use of such building materials should be instituted. This conclusion is in agreement with a general evaluation produced by EC of the possibility of exceeding 0.3 mSv y^{-1} or 1 mSv y^{-1} because of the use of certain building materials (14).

Currently, under UK legislation, radiological controls on the operation of steel production sites in the UK are confined to the atmospheric releases from the stacks. There are no restrictions on the disposal of solid wastes or the use of by-products, which relate to their radionuclide content. This position is entirely consistent with the low radiological impact of the industry as presented here. The absence of regulation is also consistent with developing EC guidance in this area. The only exception to this is the use of slag in building materials, where EC guidance indicates that future restrictions may be required. More detailed studies in this area may therefore be useful.

8 ACKNOWLEDGEMENTS

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