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RELEASES OF NATURAL RADIOACTIVITY FROM BRITISH STEEL PLANTS

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Issue 2

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SUMMARY

The report presents a compilation and review of information on the radioactive wastes arising from the operation of British Steel plants at Llanwern B and C, Port Talbot, Scunthorpe and Redcar. The radioactivity is attributable to the natural radioactivity present in low concentrations in the raw materials used in the steel making process. During the process, some of the radioactive species, particularly Pb-210 and Po-210 are concentrated into waste streams, including off-gases discharged from the stacks and solid wastes which are disposed to landfill.

On the basis of an analysis of all reported measurements of concentrations in stack discharges, and of the gas discharge rates, best estimate and upper bound estimates of the discharge rates of the two radionuclides are derived for each plant. The radiological impact of the discharges is estimated for each site, based on the results of an assessment undertaken by NRPB which is based in turn on studies of atmospheric dispersion and deposition by British Steel. For the best estimate discharge rates, the annual doses to infant members of the critical group range from about 3 μSv/y at Redcar to about 26 μSv/y from the combined Llanwern B and C plants. At the upper bound discharge rates, the estimated impacts increase to about 4 μSv/y at Redcar and to about 40 μSv/y for the combined Llanwern plants. These estimates of radiological impact are broadly confirmed by independent estimates.

A brief review of the results from environmental monitoring programmes in the vicinity of the steel plants and at control sites suggests that levels of Pb-210 and Po-210 in soil and vegetation in the vicinity of the sinter plants are probably no different to from those elsewhere in England and Wales.

The disposal of solid wastes containing an average concentration of about 10^3 Bq kg^{-1} of Pb-210 to landfill is estimated to give rise to risks of the order of 10^{-7} per year as a result of the possible redevelopment of the site for residential and horticultural use.

A comparison of the concentrations of Pb-210 and Po-210 in gaseous waste streams with exclusion limits in Schedule 1 of the RSA 93 confirms that the levels in stack discharges are such as to require authorisation under the Act. Although the concentration of Po-210 in sinter plant precipitator dust exceeds the Schedule 1 concentration for solid materials, it is well below the concentration permitted under the Phosphatic Substances Exemption Order.

1. INTRODUCTION

The raw materials used in the manufacture of iron and steel contain low levels of naturally occurring radioactivity, particularly the radioelements uranium and thorium and their progeny. During the various process steps, the radioactivity may be preferentially concentrated into waste streams, some of which are released to the environment, leading to slight increases in the radiation exposure of the public above the levels received from the natural background of radiation. The purpose of this report is to present a compilation of information to assist consideration of the possible need for authorisation under the Radioactive Substances Act 1993 (RSA 93) of discharges of waste from British Steel (BS) plants at Llanwern, Scunthorpe, Port Talbot and Redcar. This Issue 2, which supersedes Issue 1, includes the results of all stack measurements reported by BS in Appendix V of their application for authorisation under RSA 93. It also corrects a number of errors and omissions in the previous issue.

Section 2 of the report gives brief descriptions of the materials and processes involved and of the nature of the radioactive species arising in waste streams. The main waste stream of concern is the off-gas from the sinter plant which, after treatment is discharged via a chimney stack. However, sinter dust also contains low levels of radioactivity and this is disposed to landfill sites.

In Section 3, the results of measurement programmes on volume discharge rates from the sinter stacks and on the concentrations of the radioactive species Pb-210 and Po-210 are presented and discussed. The results of these programmes provide the basis of estimates of the emission rates of the nuclides to atmosphere from the plants.

The results of assessments of the dispersion of the released material in the atmosphere and its deposition to ground are discussed in Section 4 and these form the basis for the estimation, in Section 5, of the radiological impact of the released material on members of the public in the vicinity of the plants. Section 7 presents a brief summary of the results of environmental monitoring programmes in the environs of the British Steel plants and also more widely in England and Wales in order to provide a baseline for comparison. In Section 8, comparisons are made of concentrations of the two radionuclides in wastes from the processes with exclusion and exemption levels under RSA 93. The conclusions of the report are set out in Section 9.

2. BACKGROUND

A typical process flow diagram for an integrated steel production site is shown in Figure 1 (Ref 1). In the steel production process, coke produced by carbonising coal is mixed with iron ore and fluxing materials and fed to the blast furnace. However, most iron ores are too small in size to be fed directly to the blast furnace and must first be pre-treated, in a sintering stage, to achieve agglomeration.

Sintering is a heat treatment process in which the ores, mixed with coke breeze, fluxes and process recycled materials are waterbound and then fed onto a travelling cast iron grate. At the start of the grate a canopy of gas burners ignites the coke breeze within the mixture. Powerful fans draw combustion air through the sinter bed along the whole length of the grate. As the mixture proceeds along the grate, the combustion front is drawn downwards through the mixture, creating a sufficiently high temperature (about 1400°C) to convert the fine particles into a porous clinker. The gas stream is passed through an electrostatic precipitator before being discharged to atmosphere via the sinter plant stack.

At the high temperatures experienced in the production process, some of the volatile materials that are present in trace quantities in the feed materials are released into exhaust gases and released from the stack. Among the materials that are volatilised to some extent are some of the radioactive progeny of the uranium and thorium impurities present in the feedstock. The main components of the natural radioactivity releases from the stack are lead-210 (Pb-210) which is a beta emitter with a half-life of 22.3 years and which decays via the short-lived bismuth-210 (Bi-210) to polonium-210 (Po-210) which is an alpha emitter of half-life 138.4 days. Other radioactive species, including uranium, thorium and radium, have also been detected but at much lower levels and it is clear that the radiological impact of the releases will be dominated by the contributions of Pb-210 and Po-210.

Much of the radioactivity input to the plants is in very high tonnages of raw materials containing very low concentrations of natural radioactivity and this makes it difficult to get an accurate activity balance between inputs and outputs. However, in broad terms, about 5% of the Pb-210 input is subsequently discharged via the stack and about 15% of Po-210.

3. RELEASES TO ATMOSPHERE

A programme of measurements has been undertaken by British Steel to estimate release rates of the two radionuclides (Ref 1). This involved measurement of the concentration of the nuclides in samples of the stack emissions and estimation of the volume discharge rate by means of Pitot traverses of the stacks. In addition, BS commissioned a contractor - Symonds Travers Morgan (STM) - to undertake independent measurements of volume discharge rates and activity concentrations (Pb-210 only). Subsequently, further measurements of activity concentrations in stack discharges were made by other contractors on behalf of the Environment Agency (Refs 1 to 3). These were ReChem, who made measurements at Llanwern B and C and Port Talbot, and ALcontrol, who measured activity concentrations at Scunthorpe. The results of measurements commissioned by the Agency at Redcar are awaited.

3.1 Volume discharge rates

The volume discharge rates, as measured by the two organisations, are compared in Table 1 for the four sites (note that Llanwern has two stacks, B and C). This shows that, in most cases, STM record volume discharge rates higher than those of BS by up to 40%.

3.2 Activity concentrations in stack discharges

A summary of all results up to December 1997 from the measurement programme on the concentrations of Pb-210 and Po-210 in stack discharges is given in Table 2. The results for individual sites show significant variability and it is not clear whether this is due to differences in sampling and analysis techniques or to genuine variations in the radionuclide concentrations because of changes in the process or feedstock.

Mean concentrations of the two radionuclides in stack discharges from each site are shown in Table 3 on three different bases:

- average of all BS and contractor measurements;
- average of all measurements commissioned by the Environment Agency; and
- average of all measurements.

Also shown in the final column are upper limit estimates of the concentrations, based on the mean of all results plus 2 standard deviations (sd).

For the purpose of radiological assessment, it is considered that the most reasonable basis for assessing the rate of activity discharge is to use as a best estimate the mean of all measurements for a site, as in the penultimate column of Table 3, and for an upper limit estimate the mean plus 2 sd value from the final column.

3.3 Activity release rates

On the basis of the volume discharge rates measured by BS (Table 1), the estimated release rates for Pb-210 and Po-210 from each site are given in Table 4, in units of Bq per second, for both the mean and the mean plus 2 sd concentrations from Table 3.

4. ATMOSPHERIC DISPERSION

4.1 British Steel calculations

In order to provide a basis for radiological assessments, to be undertaken by the National Radiological Protection Board (NRPB), British Steel undertook dispersion modelling using the ADMS code. At the outset, NRPB examined local maps and identified the positions of the nearest residential area and the nearest farm to each of the sites. For each of these locations, BS calculated the average annual ground level air concentrations (Bq/m^3) and average annual deposition (Bq/m^2 s), for a continuous emission rate of 1 Bq/s. The calculations were performed for a particle AMAD of 1 μm using the stack emission characteristics (velocity, flow rate, temperature) obtained by both BS and STM. The results are shown in Annex 1 (Ref 1).

The results show that, generally, the concentrations at ground level per unit activity release are lower when they are based on a higher volume discharge rate. This seems likely to be an effect related to the discharge velocity; a higher velocity giving a greater effective stack height. This is illustrated in the following comparison based on the Llanwern B results.

Basis of discharge characteristics	BS	STM
Volume discharge rate, m^3 s^{-1}	144.1	205.5
Annual average air conc., Bq m^3	1.2×10^{-8}	8×10^{-9}

The overall result of this effect is that the higher activity release rates calculated from the STM volume discharge rate are off-set by the greater dispersion leading to a similar ground level concentration, at least at short range.

On the other hand, the results in Annex 1 show that, at Llanwern B, the annual average deposition rate per unit activity release rate is essentially independent of the emission characteristics and therefore proportional to the activity release rate.

For Port Talbot, because of the topography of the site, BS ran dispersion calculations based on both a flat terrain model using Rhoose meteorological data and also based on a hilly terrain model using a selected subset of the Rhoose data. The results obtained using both BS and STM emission characteristics are given in Annex 1. Although there are differences in the results of calculations based on BS and STM emission data, these are small in relation to differences attributable to the different modelling basis and also the two locations. The results based on BS emission characteristics are shown in Table 5 for a release rate of 1 Bq/s.

The significant points to be noted from these data are that:

- using the flat terrain model, the average concentration increases by some 75% from the residential site at 1.2 km to the arable site at 2 km, but the deposition rate decreases by about 20%;

- the hilly terrain model gives a higher concentration in air at the shorter range (i.e. the residential site) and a reduced concentration at the arable site; and

- the ratio of the deposition rate to the concentration in air is markedly lower at the arable site when based on the hilly terrain model.

These observations illustrate a difficulty with the use of ADMS, which is that the behaviour of the system, and hence the results, are much less intuitive than for the simpler Gaussian plume models. However, it is apparent that the results are very sensitive to the modelling approach and the selection of data. From the point of view of the radiological assessment, the key result in the above table is the deposition rate to arable land since the radiological impact is proportional to this value, see Section 5. That the value of this parameter is a factor of 30 lower for the hilly than the flat terrain model, and a factor of almost 50 lower at the arable than the residential location (using the hilly terrain model) is a matter for concern and raises questions as to the robustness of the calculations, at least for the Port Talbot site.

4.2 CERC calculations

In order to provide verification of the BS calculations, the Environment Agency commissioned Cambridge Environmental Research Consultants (CERC) to undertake independent calculations; these were also performed using the ADMS code. The CERC calculations considered two alternative sets of meteorological data - seasonal (representing the growing season for agricultural produce) and annual. These results showed that the use of data corresponding to the growing season results in concentrations higher by between 17% and 30% than for annual average meteorology.

The CERC calculations (Ref 4) were based on a particle size of 0.5 μm and the comparison with the BS estimates for 1 μm particle size is discussed below.

4.3 Comparison of BS and CERC dispersion calculations at arable site

Table 6 shows a comparison of the results of the BS and CERC calculations for the five sites. The results are for unit activity release rate and apply at the nearest farm to each site (as identified by NRPB). For consistency, the CERC results shown are based on BS emission characteristics, annual meteorology and a particle size of 0.5 μm.

The comparison shows that, other than at Llanwern B, there is very good agreement between the BS and CERC estimates of the concentration in air at ground level for unit release rate. At Llanwern B, the CERC estimate is about 14 times the BS value.

As was noted earlier, the important parameter in the context of the radiological assessment is the ground deposition rate and it can be seen that there is good agreement on the value of this even at Llanwern B.

Although these studies indicate some difficulties in obtaining consistent results for the dispersion and deposition of material released from stacks, particularly at locations of complex topography, the results of the comparisons are encouraging and suggest that the results can be considered reliable to within a factor of two to three.

4.4 Basis for radiological assessment

Subsequent to the studies discussed above, NRPB adopted slightly modified values of the dispersion and deposition parameters (Ref 5). The main difference being that for the purpose of estimating the dose via food pathways, the deposition rate used for each site represented an average value over several farms. The effect of this is to reduce the value of the deposition parameter by a factor of up to about two.

The values used by NRPB are shown in Table 7, which also shows for comparison the original estimates by BS.

5. RADIOLOGICAL ASSESSMENT

British Steel commissioned NRPB to undertake an assessment of the radiological impact on members of the public of unit releases of Pb-210 and Po-210 from each of the five stacks, based on both the BS and STM measurements of volume discharge rates. The effects of differences in the dispersion and deposition resulting from the two sets of volume measurements have been discussed in the previous section and subsequent discussion is based only on the BS data. The basis and results of the NRPB assessment for unit release rate from each of the stacks are discussed in Section 5.1 below.

As part of the present review, a limited independent radiological assessment has been undertaken in order to assist an appreciation of the uncertainties in the estimated impacts of the plants. The results of the calculations are summarised in Section 5.2.

The current assessment of the radiological impact of releases from the five BS sites is presented in Section 5.3 and the uncertainties and implications are discussed.

In all cases, the assessments are based on the levels of radioactivity in the environment that would result from releases from the plants at current rates over a period of 50 years.

5.1 NRPB assessment

5.1.1 Basis

The results of the assessment are reported in Ref 5 which covers the assessment of individual dose and in Ref 6 which presents the results of the assessment of collective does to the UK and European populations from the releases.

In the assessment of individual doses, annual dose rates were calculated for infants (1 year), children (10 years) and adults from external radiation, from inhalation of activity from the plume and from ingestion of locally grown foodstuffs. The dose from food consumption is estimated on the pessimistic basis that essentially all food consumed by the critical exposure group is produced locally. The standard UK approach is adopted in relation to the critical group consumption rate; this is that most foodstuffs are consumed at the national average rate appropriate to the age group, but that the two food products that make the highest contributions to the dose, in this case milk and root vegetables, are assumed to be consumed at rates corresponding to the 97.5th percentile level, see Table 8. The dosimetry is based on ICRP60, using dosimetric factors from ICRP72.

As discussed in Section 4, average annual air concentrations and deposition rates are defined for a number of receptor points at each site, covering both residential locations and areas of agricultural production. In the latter case, mean deposition rates have been calculated for each site by averaging over several locations (ie farms). At Llanwern, the result of this procedure is that the average deposition rate, on which dose calculations are based, is about half of the value at the limiting site (Barn Farm). For the other sites, the deposition rates are similar at all of the identified locations and so use of the average values does not significantly underestimate the impact at any location.

The radiological impact is dominated by food pathways and these have been assessed using the FARMLAND model.

5.1.2 Results

The results of the assessment for unit release rate from each of the stacks are shown in Table 9. Differences in the dose estimates for the three age groups arise from both the dosimetric factors and the assumed ingestion rates of locally-grown foodstuffs. For the inhalation and external dose contributions the differences in the dose estimates for the three age groups are relatively small. Compared to an adult, the dose to a 10-year old is higher by about 5% and to an infant the dose is lower by about 15%. However, for the more important ingestion route the doses to the infant and the 10-year old are about 100% and 40%, respectively, higher than the adult.

5.2 Independent assessment

5.2.1 General approach

In order to assist in gaining an appreciation of the uncertainties in the overall assessment, a limited independent radiological assessment has been undertaken as part of the present review. Calculations were undertaken for adults only and based on ICRP60 dosimetry.

Models such as FARMLAND contain a mathematical representation of agricultural systems and the processes of radionuclide transfer through the system from initial deposition to harvesting are represented by various transfer parameters, such as a soil to plant concentration factors. The parameter values are taken from databases and from compilations in the literature. The main difficulty is that for both lead and polonium the transfer parameters are not well characterised, often ranging over one to two orders of magnitude.

Because of this difficulty, the independent assessment was based on a semi-empirical approach making use of information on Pb-210 and Po-210 levels in the natural environment. It is known (Ref 7) that the levels of these radionuclides in natural vegetation and in crops (and hence in animal products) is attributable mainly to direct deposition of the decay products of radon, rather than to uptake from soil, and the processes of activity transfer will therefore be similar to those applying to activity released from stacks. The approach adopted was therefore to estimate the concentrations in soil and vegetation due to activity deposited from the plume and then to derive the levels in crops and animal products by comparisons with levels observed in the natural environment.

5.2.2 Levels of Pb-210 and Po-210 in the natural environment

Sandalls (Ref 7) reviewed data on measured levels of the two radionuclides in soil and herbage in rural and in urban/industrial locations in the UK. The levels observed in the two types of areas were found not to differ significantly and mean background concentrations in soil and herbage were estimated for England and Wales. The derived values are, in Bq kg^{-1} dry weight (dw):

	Pb-210	Po-210
Soil	26 ± 14	24 ± 16
Herbage	22 ± 14	14 ± 16

Expressed on a fresh weight (fw) basis and using a typical dw/fw ratio of 0.1, herbage becomes:

	2.2 ± 1.4	1.4 ± 1.6

A review and summary of measurements of concentrations of the nuclides in UK terrestrial foodstuffs was reported by McDonald (Ref 8) in 1995. An analysis of the data is shown in Table 10, which gives the mean and mean + 2 sd values. For milk, ranges of values were reported as 0.004 to 0.035 for Pb-210 and 0.011 to 0.015 for Po-210 (Bq l^{-1}). On the basis of these limited data, values equivalent to the mean and mean + 2 sd values are estimated and also shown in Table 10. These values provide an empirical basis for estimating concentrations in food products from an estimate of the concentration in grass.

5.2.3 Assessment of dose

Using this semi-empirical approach, the annual dose rates to adults from ingestion of locally produced foodstuffs are derived, using the same consumption data as in the NRPB assessment, for unit deposition rate to ground (1 Bq m^{-2} s^{-1}) of Pb-210 and Po-210. These results and the equivalent NRPB results are shown below in units of Sv y^{-1} per Bq m^{-2} s^{-1}

	NRPB	**Independent calculations**
Pb-210	11	16
Po-210	54	19

The results can be regarded as being in excellent agreement, particularly for Pb-210. The factor of three difference between the two sets of results for Po-210 is not in itself very significant, but taking into account that the empirical derivation of concentrations in foodstuffs has been made on a conservative basis from the mean + 2 sd values of measured concentrations, the indications are that the NRPB estimates could be conservative.

Applying the results to a specific site, Llanwern B, for a unit release rate of 1 Bq s^{-1} the comparison of the estimates is shown in Table 11. The good agreement between the two assessments provides assurance that the results presented by NRPB are robust and the following discussion of the radiological impact of discharges at the rates measured for the five plants is based on the NRPB estimates.

5.3 Current assessment of radiological impact

The estimated impacts of discharges of the two nuclides from the five stacks, based on the NRPB assessment results for the BS volume release rates, are shown in Table 12 for the best estimate discharges and in Table 13 for the mean + 2 sd discharges.

The results show that for the best estimate discharge rates, the estimated impacts of Pb-210 and Po-210 releases from BS sinter plants on infant members of the critical group range from 3.2 μSv/y at Redcar to about 26 μSv/y from the combined Llanwern B and C plants.

For the mean + 2 sd discharge rates, the estimates are increased by around 60% and range from 4 μSv/y at Redcar to about 40 μSv/y from the combined Llanwern plants.

The estimates for most sites are based on average dispersion at a number of locations where average air concentrations and ground deposition rates are similar. At Llanwern this results in underestimation of the impact at the limiting location, Barn Farm, which will be about twice that shown in the table, *i.e.* the dose to infants whose diet consists essentially of food produced at this location would be about 50 μSv/y. However, it should be noted that for the two foodstuffs making the largest contributions to dose, milk and root vegetables, consumption rates at the 97.5th percentile level are assumed in the NRPB estimates, with other foodstuffs consumed at average rates. These consumption patterns are clearly very conservative.

Estimates have also been made by NRPB of the collective dose to the UK and European populations from unit emission rate from the five sinter stacks (Ref 6). Based on these estimates, the collective radiological impact from the best estimate and mean + 2 sd discharges are shown in Tables 12 and 13. The estimates are of collective effective dose, truncated to 500 years. The results show that the collective dose commitment from one year of operation of each of the four sites (taking Llanwern B and C as a single site) is in the range 0.7 to 2.1 man-Sv to the UK population and 1.8 to 3.7 man-Sv to the European (including the UK) population.

5.4 Discussion

The results presented in this section show good agreement between the NRPB assessment, based on use of the FARMLAND model, and an independent assessment undertaken as part of this review and using a different approach. This similarity of the results is not entirely surprising since the modelling parameters used in the FARMLAND model derive from reviews of the environmental behaviour of the radionuclides. Nevertheless, that the more direct use of the monitoring data gives similar results serves to increase confidence that the impacts are not being underestimated to any significant extent. The indications are that the opposite may be the case and that, particularly for Po-210, the NRPB results may be quite conservative.

Information presented in Section 6 below from environmental monitoring programmes tends to support the latter view and suggests that both of the modelling assessments discussed in this section may be significantly over-estimating the radiological impact.

6. ENVIRONMENTAL MONITORING

A programme of soil core sampling and analysis in the vicinity of Llanwern was undertaken by British Steel in 1996 and the radiometric measurement of the cores for Pb-210 and Po-210 was performed by NRPB (Ref 1). The results of the monitoring programme are shown in Table 14 and indicate that the Po-210 is in equilibrium with Pb-210. Samples 7 and 8 show higher concentrations of both nuclides but it is not possible to deduce whether this is attributable to the emissions from the sinter plant. Both samples were from locations about 3 km to the west of the stacks but at locations well beyond the distance at which maximum deposition would be expected to occur.

The results of a programme of environmental sampling in the vicinity of the British Steel sinter plants, undertaken on behalf of the Environment Agency, are reported in Ref 7. The samples included surface soil, grass, weeds, leaves, road dust and pond waters, and were analysed for Pb-210 and Po-210 by the Laboratory of the Government Chemist and ICI Tracerco. The reference also includes a compilation of data on levels of the radionuclides in soil and vegetation at UK locations remote from the British Steel sites, and derives background levels for urban/industrial areas and rural/semi-rural areas. It was found that the mean levels at the urban/industrial areas and rural/semi-rural areas were almost identical and overall mean background concentrations were derived.

The principal results of the sampling programmes in the vicinity of the plants are summarised in Table 15, which also shows, for comparison, the derived mean background concentrations. Within the natural variabilities and analytical uncertainties, the reported levels of Pb-210 in soil at Llanwern, Port Talbot and Redcar were within the range of the derived background level. The value of less than 10 Bq kg^{-1} is unusually low. Similarly, the reported levels of Po-210 in soil at Port Talbot and Redcar were within the range of the background level. Those at Llanwern and Scunthorpe were within the background range and probably lower than the Pb-210.

The concentrations of the two radionuclides in samples of vegetation were within the range of the derived background, though the level of Pb-210 of 57 ± 29 at Llanwern is quite high.

It was concluded in Ref 7 that the available data show that levels of Pb-210 and Po-210 in soil and vegetation in the vicinity of the sinter plants are probably no different to from those elsewhere in England and Wales.

Scoping calculations for the combined effects of Llanwern B and C, based on the deposition flux estimates of British Steel, suggest that continuous stack discharge at the mean + 2 sd rates would result in concentrations in soil of each nuclide after 50 years of operation of less than 1 Bq kg^{-1}, *i.e.* an increase of at most 5% over the background level. Similarly, the increase in the concentrations in vegetation are estimated to be less than 1.0 Bq kg^{-1}, or about 7% of the background level, after 50 years of discharge. This illustrates the difficulty of measuring a small increment in the environmental levels of the two radionuclides against the much larger but inherently variable natural background. However, these considerations also suggest that the radiological impact of the discharges from the combined Llanwern plants would be at most 5 to 10 percent of the dose from the background levels of the radionuclides.

An assessment of the radiological impact of Pb-210 and Po-210 in terrestrial foodstuffs consumed at both average and critical group rates in the UK is reported in Ref 8. This indicated a dose of 160 μSv/y to infants consuming at critical group rates. The implication of this estimate is that the dose to infants in the vicinity of the Llanwern plants would be at most 10 to 15 μSv/y, suggesting that the NRPB assessment contains some degree of conservatism.

7. DISPOSAL OF SOLID WASTES

Most of the Pb-210 and Po-210 activity in solid wastes arising at the steel works is in hydrocyclone slurries and electrostatic precipitator dusts arising from off-gas treatment. At the time of disposal, these wastes have an average Pb-210 concentration of about 10^3 Bq kg^{-1} at the time of disposal. Regardless of the initial concentration of Po-210, this nuclide reaches equilibrium with Pb-210 within about a year.

An assessment by NRPB of the radiological impact of the disposal of the wastes to a landfill site is reported in Ref 5. The assessment considers various scenarios of radiation exposure of workers and members of the public resulting from the presence of the landfill. It is shown that the limiting scenario is one in which the site is excavated for residential redevelopment and that all vegetables consumed by the residents are grown on the contaminated land. The dose estimates are based on the assumptions that the vegetables are grown in the undiluted radioactive dust and are consumed at the national average consumption rates.

The assessment is based on a nominal total activity of 1 GBq of Pb-210 in a volume of 2×10^5 m^3 of density 1.5 t m^{-3}, corresponding to an initial activity concentration of 3.3 Bq kg^{-1}. Results are presented for the dose rates that would result from residence on and consumption of vegetables from the redeveloped site at times of 30, 50, 100 and 300 years. For the redevelopment of the site after 30 years, the estimated dose rate from the nominal activity concentration is 1.2 μSv y^{-1}. The annual probability of such a mode of site development is estimated by NRPB to be 5.4 x 10^{-4} y^{-1}, and applying a factor of 0.05 Sv^{-1} for the probability of a serious health effect, the risk is estimated to be 3.3 x 10^{-11} y^{-1}.

For the typical concentration of 10^3 Bq kg^{-1} in the wastes, the dose rate for redevelopment of the site at 30 years would be about 370 μSv y^{-1} and, on the NRPB basis, the risk would be about 1.2 x 10^{-8} y^{-1}.

A more usual formulation of risk would require that the calculation of risk at any time takes account of the cumulative probability that redevelopment of the site will have occurred by that time. The effect of this would be to increase the risk estimated by NRPB by a factor of 10 to 20, depending on modelling assumptions. On this basis, the risk estimate at 30 years would be in the range 1 to 2 x 10^{-7} y^{-1}.

The government has specified a risk target for disposals of solid wastes to specialised facilities for the disposal of low and intermediate level radioactive wastes of 10^{-6} per year. Although this target is not specifically intended to apply to general landfill operations it provides a useful benchmark against which to consider the acceptability of the disposal operations. Whilst the level of risk is well below the target for specialised disposal facilities, it may be noted that a more important consideration in this case might be the dose rate that would result from redevelopment of the site.

8. COMPARISON OF WASTES WITH EXCLUSION AND EXEMPTION LEVELS

Under the Radioactive Substances Act 1993, wastes containing concentrations of the naturally occurring radionuclides at concentrations below those specified in Schedule 1 to the Act are not considered to be radioactive waste and are not subject to authorisation under the Act. In addition, the Radioactive Substances (Phosphatic Substances, Rare Earths etc.) Exemption Order 1962 excludes from the requirement for authorisation radioactive waste containing only the Schedule 1 radioelements in a solid form and substantially insoluble in water up to a higher concentration than specified in Schedule 1. The relevant Schedule 1 concentration limits for solid and gaseous and the limits for solid forms under the Exemption Order are shown in Table 16 which also shows the typical concentrations in the waste streams from the BS plants.

The comparison of the concentrations of Pb-210 and Po-210 in gaseous waste streams with the exclusion limits in Schedule 1 confirms that the levels in stack discharges are such as to require authorisation under the Act. Although the concentration of Po-210 in sinter plant precipitator dust exceeds the Schedule 1 concentration for solid materials, it is well below the concentration permitted under the Phosphatic Substances Exemption Order.

9. CONCLUSIONS

This report has presented a compilation and review of information on the radioactive wastes arising from the operation of British Steel plants at Llanwern B and C, Port Talbot, Scunthorpe and Redcar. The radioactivity is attributable to the natural radioactivity present at low concentrations in the raw materials used in the steel making process. During the process, some of the radioactive species, particularly Pb-210 and Po-210 are concentrated into waste streams, including off-gases discharged from the stacks and solid wastes which are disposed to landfill.

On the basis of an analysis of all reported measurements of concentrations in stack discharges, and of the volume discharge rates, best estimate and upper bound estimates of the discharge rates of the two radionuclides are derived for each plant. The radiological impact of the discharges is estimated for each site, based on the results of an assessment undertaken by NRPB which is based in turn on studies of atmospheric dispersion and deposition by British Steel. For the best estimate discharge rates, the annual doses to infant members of the critical group range from about 3 μSv/y at Redcar to about 26 μSv/y from the combined Llanwern B and C plants. At the upper bound discharge rates, the estimated impacts increase to 4 μSv/y at Redcar and to about 40 μSv/y for the combined Llanwern plants. These estimates of radiological impact are broadly confirmed by independent estimates.

A brief review of the results from environmental monitoring programmes in the vicinity of the steel plants and at control sites suggests that levels of Pb-210 and Po-210 in soil and vegetation in the vicinity of the sinter plants are probably no different to from those elsewhere in England and Wales. Estimates are reported in the literature of the dose resulting from consumption of food produce containing natural levels of Pb-210 and Po-210 and, from these, the dose that could result from the releases from the steel plants can be inferred. These suggest that the results obtained from both the NRPB assessment and the assessment undertaken as part of this review may be regarded as upper bound estimates of radiological impact.

The disposal of solid wastes containing an average concentration of about 10^3 Bq kg^{-1} of Pb-210 to landfill is estimated to give rise to risks of the order of 10^{-7} per year as a result of the possible redevelopment of the site for residential and horticultural use.

A comparison of the concentrations of Pb-210 and Po-210 in gaseous waste streams with exclusion limits in Schedule 1 of the RSA 93 confirms that the levels in stack discharges are such as to require authorisation under the Act. Although the concentration of Po-210 in sinter plant precipitator dust exceeds the Schedule 1 concentration for solid materials, it is well below the concentration permitted under the Phosphatic Substances Exemption Order.

10. REFERENCES

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Site	Volume discharge rate, m^3/s	
	British Steel	SymondsTravers Morgan
Llanwern B	144.1	205.5
Llanwern C	126.4	142.1
Port Talbot	305.0	435.5
Scunthorpe	351.7	330.5
Redcar	225.5	292.3

TABLE 1: VOLUME DISCHARGE RATES AS MEASURED BY BS AND STM

Site	Sample identity or date	Sampled/ analysed	Bq m^{-3}	
			Pb-210	Po-210
Llanwern B	L6F 134	BS	-	2.92
	L6F 141	BS	2.29	-
	L6F 352	BS	1.37	4.26
	L6F 353	BS	0.98	3.37
	L7F 530	BS	0.64	3.08
	L7F 531	BS	0.69	3.14
	L7F 532	BS	-	3.19
	L6F 080	STM	-	4.37
	17 June 1996	ReChem/EA	1.75	2.5
	20 June 1996	ReChem/EA	1.78	2.8
Llanwern C	LL RAL1	BS	-	3.07
	L6F 339	BS	2.37	4.78
	L6F 340	BS	4.02	6.21
	L6F 354	BS	-	-
	L6F 355	BS	1.46	3.89
	L6F 356	BS	-	-
	L6F 357	BS	1.38	3.42
	L7F 527	BS	0.89	3.04
	L7F 528	BS	-	3.41
	L7F 529	BS	-	3.2
	L6F 084	STM	-	5.81
	11 June 1996	ReChem/EA	2.04	3.2
	12 June 1996	ReChem/EA	2.24	3.4

TABLE 2: SUMMARY OF MONITORING RESULTS FOR Pb-210 AND Po-210 (Cont)

Site	Sample date	Sampled/ analysed	Bq m^{-3}	
			Pb-210	Po-210
Port Talbot	L6F092	STM	-	4.01
	L6F393	STM	-	4.11
	L6F394	STM	-	3.48
	L6F395	STM	0.14	2.86
	(ICI) 88164	ReChem/EA	2.23	4.04
	(ICI) 88165	ReChem/EA	2.63	4.31
Scunthorpe	L6C175	BS	-	1.67
	L6C176	BS	0.32	-
	L6C178	BS	-	5.74
	L6C179	BS	1.03	-
	L6C180	BS	0.43	-
	L6C181	BS	-	3.58
	SC25814	BS	-	3.19
	SC25814	BS	-	1.83
	SC231009	BS	0.47	1.53
	L6F035	BS	-	2.85
	L6F276	BS	-	1.07
	L6F277	BS	-	2.73
	L6F315	BS	-	-
	L6F316	BS	1.31	2.86
	L6F351	BS	0.73	1.61
	PF97047	BS	-	3.5
	PF97065	BS	-	2.77
	L6F 088	STM	-	2.93
	1997	ALcontrol/EA	0.37	1.30
	1997	ALcontrol/EA	0.38	1.44
	1997	ALcontrol/EA	0.36	1.04
	1997	ALcontrol/EA	0.34	1.23
Redcar	TS12120X	BS	0.48	3.64
	L6F040	BS		3.50
	L6F324	BS	1.99	-
	L6F096	STM	-	4.03

TABLE 2 (Cont):

SUMMARY OF MONITORING RESULTS FOR Pb-210 AND Po-210

Site	Nuclide	Concentrations in stack discharge, Bq m^{-3}			
		Mean measured concentration			Mean [(1)] plus 2 sd
		BS and Contractors	EA and Contractors	All results	
Llanwern B	Pb-210	1.19	1.76	1.35	2.59
	Po-210	3.33	2.65	3.29	4.56
Llanwern C	Pb-210	2.02	2.14	2.06	4.09
	Po-210	4.09	3.32	3.95	6.22
Port Talbot	Pb-210	014	2.43	1.67	4.34
	Po-210	3.61	4.18	3.80	4.88
Scunthorpe	Pb-210	0.71	0.36	0.57	1.26
	Po-210	2.70	1.25	2.38	4.79
Redcar	Pb-210	1.24	-	1.24	3.37
	Po-210	3.72	-	3.72	4.27

Note: 1. Based on all measurements

TABLE 3: AVERAGE MEASURED CONCENTRATIONS OF Pb-210 AND Po-210 IN STACK DISCHARGES

		Stack discharge rate, Bq/s	
		Mean (all data)	Mean plus 2 sd
Llanwern B	Pb-210	195	373
	Po-210	474	657
Llanwern C	Pb-210	260	516
	Po-210	499	786
Port Talbot	Pb-210	508	1324
	Po-210	1160	1489
Scunthorpe	Pb-210	202	442
	Po-210	838	1685
Redcar	Pb-210	278	760
	Po-210	840	963

Note: Based on averages of all measurements and on volume discharge rates as measured by BS

TABLE 4: ACTIVITY RELEASE RATES

Modelling basis	Location	Annual average concentration Bq m^{-3}	Annual average deposition rate Bq m^{-2} s^{-1}	Ratio of deposition rate to concentration m s^{-1}
Flat (Rhoose data)	Residential (1.2 km NE)	4.7×10^{-9}	1.96×10^{-10}	0.04
	Arable (2 km NE)	8.2×10^{-9}	1.55×10^{-10}	0.019
Hilly (Rhoose subset)	Residential (1.2 km NE)	1.1×10^{-8}	2.36×10^{-10}	0.021
	Arable (2 km NE)	2.5×10^{-9}	5.0×10^{-12}	0.002

Notes: (1) Based BS emission characteristics and unit emission rate.

TABLE 5: COMPARISON OF DISPERSION CALCULATIONS FOR PORT TALBOT USING FLAT AND HILLY TERRAIN MODELS

Stack	Air concentration Bq m^{-3}		Ground deposition rate Bq m^{-2} s^{-1}	
	BS	CERC	BS	CERC
Llanwern B	1.2×10^{-8}	1.6×10^{-7}	3.5×10^{-10}	4.4×10^{-10}
Llanwern C	2.8×10^{-8}	3.4×10^{-8}	3.3×10^{-10}	2.3×10^{-10}
Port Talbot(1)	8.2×10^{-9}	9.0×10^{-9}	1.6×10^{-10}	1.7×10^{-10}
Scunthorpe	4.3×10^{-9}	4.5×10^{-9}	2.6×10^{-11}	2.8×10^{-11}
Redcar(2)	3.4×10^{-9}	4.1×10^{-9}	2.4×10^{-11}	1.9×10^{-11}

Notes: (1) Based on meteorological data for Rhoose and flat terrain.
(2) Based on meteorological data for Boulmer.

TABLE 6: COMPARISON OF AIR CONCENTRATIONS AND GROUND DEPOSITION RATES CALCULATED BY BS AND CERC FOR UNIT EMISSION RATE

		Annual average air concentration Bq m^{-3} (1)	Annual average deposition rate Bq m^{-2} s^{-1} (2)
Llanwern B	NRPB	3.2×10^{-8}	2.3×10^{-10}
	BS	8.4×10^{-9}	3.5×10^{-10}
Llanwern C	NRPB	2.1×10^{-8}	1.6×10^{-10}
	BS	9.7×10^{-9}	3.3×10^{-10}
Port Talbot (3)	NRPB	1.4×10^{-8}	6.8×10^{-11}
	BS	4.7×10^{-9}	1.6×10^{-10}
Scunthorpe	NRPB	5.4×10^{-9}	3.6×10^{-11}
	BS	4.3×10^{-9}	2.6×10^{-11}
Redcar (4)	NRPB	8.4×10^{-9}	2.7×10^{-11}
	BS	8.4×10^{-9}	2.4×10^{-11}

Notes: 1. At residential location
2. At agricultural location, NRPB results are averages over several farms
3. Results based on Rhoose meteorology and flat terrain model
4. Boulmer meteorology

TABLE 7: NRPB BASIS FOR RADIOLOGICAL ASSESSMENT AND COMPARISON WITH ORIGINAL BS ESTIMATES (ALL RESULTS FOR EMISSION RATE OF 1 Bq s^{-1})

Foodstuff	Consumption rate, kg per year (1)		
	Infant	Child	Adult
Green vegetables	5	10	30
Grain	15	45	50
Root vegetables	45	95	130
Fruit	7.5	15	15
Beef	3	10	15
Cow liver	0.2	0.5	1
Milk products	15	15	20
Milk	320	240	240
Lamb	0.6	1.5	3
Sheep liver	0.2	0.5	1

Note: 1. These are national average values except for milk and root vegetables which are 97.5 percentile values.

TABLE 8: FOOD CONSUMPTION RATES FOR CRITICAL GROUP

Site	Pathway	Annual dose, μSv per Bq s^{-1}					
		Infant		Child		Adult	
		Pb-210	Po-210	Pb-210	Po-210	Pb-210	Po-210
Llanwern B	Inhal + ext	2.3×10^{-4}	7.0×10^{-4}	2.7×10^{-4}	8.4×10^{-4}	2.7×10^{-4}	7.9×10^{-4}
	Ingestion	7.1×10^{-3}	2.8×10^{-2}	5.8×10^{-3}	2.1×10^{-2}	2.7×10^{-3}	1.3×10^{-2}
	Total	7.3×10^{-3}	2.9×10^{-2}	6.0×10^{-3}	2.1×10^{-2}	3.0×10^{-2}	1.4×10^{-2}
Llanwern C	Inhal + ext	1.5×10^{-4}	4.5×10^{-4}	1.8×10^{-4}	5.4×10^{-4}	1.7×10^{-4}	5.1×10^{-4}
	Ingestion	4.7×10^{-3}	1.9×10^{-2}	3.8×10^{-3}	1.4×10^{-2}	1.8×10^{-3}	8.8×10^{-3}
	Total	4.9×10^{-3}	1.9×10^{-2}	4.0×10^{-3}	1.4×10^{-2}	2.0×10^{-3}	9.3×10^{-3}
Port Talbot (1)	Inhal + ext	1.0×10^{-4}	3.0×10^{-4}	1.2×10^{-4}	3.6×10^{-4}	1.2×10^{-4}	3.4×10^{-4}
	Ingestion	2.1×10^{-3}	8.3×10^{-3}	1.7×10^{-3}	6.0×10^{-3}	8.0×10^{-4}	3.8×10^{-3}
	Total	2.2×10^{-3}	8.6×10^{-3}	1.8×10^{-3}	6.4×10^{-3}	9.2×10^{-4}	4.2×10^{-3}
Scunthorpe	Inhal + ext	3.8×10^{-5}	1.2×10^{-4}	4.5×10^{-5}	1.4×10^{-4}	4.4×10^{-5}	1.3×10^{-4}
	Ingestion	1.0×10^{-3}	4.1×10^{-3}	8.4×10^{-4}	3.0×10^{-3}	4.0×10^{-4}	1.9×10^{-3}
	Total	1.1×10^{-3}	4.2×10^{-3}	8.8×10^{-4}	3.1×10^{-3}	4.4×10^{-4}	2.1×10^{-3}
Redcar (2)	Inhal + ext	5.9×10^{-5}	1.8×10^{-4}	7.0×10^{-5}	2.2×10^{-4}	6.9×10^{-5}	2.0×10^{-4}
	Ingestion	8.3×10^{-4}	3.3×10^{-3}	6.7×10^{-4}	2.4×10^{-3}	3.2×10^{-4}	1.5×10^{-3}
	Total	8.9×10^{-4}	3.5×10^{-3}	7.4×10^{-4}	2.6×10^{-3}	3.9×10^{-4}	1.7×10^{-3}

Notes: 1. Based on flat terrain model.
2. Based on Boulmer meteorology

TABLE 9: RESULTS OF NRPB ASSESSMENT OF RADIOLOGICAL IMPACT FOR UNIT RELEASE RATE (From Ref 5)

Food product	No. of measurements	Concentration, Bq kg^{-1} fw			
		Pb-210		Po-210	
		Mean	Mean + 2sd	Mean	Mean + 2sd
Green vegetables	9	0.13	0.31	0.066	0.17
Root crops	6	0.01	0.023	0.0043	0.014
Grain	15	0.31	0.71	0.23	0.58
Liver	5	0.85	1.9	1.1	3.2
Following value based on range of reported measurements					
Milk	-	0.01	0.035	0.013	0.04

TABLE 10: ANALYSIS OF MEASURED CONCENTRATIONS IN FOOD PRODUCTS

	Annual dose, μSv per Bq s^{-1} (1)			
	NRPB		This review	
	Pb-210	Po-210	Pb-210	Po-210
Inhalation Ingestion	2.7×10^{-4} 2.7×10^{-3}	7.9×10^{-4} 1.3×10^{-2}	3.2×10^{-4} 3.9×10^{-3}	1.1×10^{-3} 4.4×10^{-3}
Total	3.0×10^{-3}	1.4×10^{-2}	4.2×10^{-3}	5.5×10^{-3}

Note: 1. Dose to adult member of critical group.

TABLE 11: COMPARISON OF ESTIMATES OF IMPACT FOR UNIT RELEASE RATE FROM LLANWERN B

		Individual dose, uSv/y			Collective dose Man-Sv/y	
		Infant	Child	Adult	UK	Europe
Llanwern B	Pb-210	1.4	1.2	0.6	0.10	0.35
	Po-210	13.8	10.0	6.6	0.57	1.42
	Total	15.2	11.1	7.2	0.67	1.77
Llanwern C	Pb-210	1.3	1.0	0.5	0.13	0.44
	Po-210	9.5	7.0	4.6	0.60	1.45
	Total	10.8	8.0	5.2	0.73	1.89
Llanwern B and C		25.9	19.2	12.4	1.4	3.7
Port Talbot	Pb-210	1.1	0.9	0.5	0.18	0.71
	Po-210	10.0	7.4	4.9	1.06	2.90
	Total	11.1	8.3	5.3	1.24	3.61
Scunthorpe	Pb-210	0.2	0.2	0.1	0.18	0.34
	Po-210	3.5	2.6	1.8	1.93	3.27
	Total	3.7	2.8	1.8	2.1	3.61
Redcar	Pb-210	0.2	0.2	0.1	0.08	0.33
	Po-210	2.9	2.2	1.4	0.61	2.1
	Total	3.2	2.4	1.5	0.69	2.43

TABLE 12: RADIOLOGICAL IMPACT OF STACK RELEASES FROM SINTER PLANTS - BASED ON MEAN DISCHARGE RATES

Site	Nuclide	Individual dose, uSv/y			Collective dose Man-Sv/y	
		Infant	Child	Adult	UK	Europe
Llanwern B	Pb-210	2.7	2.2	1.1	0.19	0.67
	Po-210	19.0	13.8	9.2	0.79	1.97
	Total	21.8	16.0	10.3	0.98	2.64
Llanwern C	Pb-210	2.5	2.1	1.0	0.26	0.88
	Po-210	14.9	11.0	7.3	0.94	2.28
	Total	17.5	13.1	8.3	1.2	3.16
Llanwern B and C		39.2	29.1	18.7	2.2	5.8
Port Talbot	Pb-210	1.7	1.4	0.7	0.28	1.11
	Po-210	12.8	9.5	6.3	1.36	3.72
	Total	14.5	11.0	7.0	1.64	4.83
Scunthorpe	Pb-210	0.5	0.4	0.2	0.39	0.75
	Po-210	7.1	5.2	3.5	3.88	6.57
	Total	7.6	5.6	3.7	4.26	7.32
Redcar	Pb-210	0.7	0.6	0.3	0.21	0.91
	Po-210	3.4	2.5	1.6	0.70	2.41
	Total	4.0	3.1	1.9	0.91	3.32

TABLE 13: RADIOLOGICAL IMPACT OF STACK RELEASES FROM SINTER PLANTS - BASED ON MEAN DISCHARGE RATES PLUS 2 STANDARD DEVIATIONS

Sample No	Grid ref	Concentration in soil Bq kg^{-1} (dry) $\pm 2\sigma$		Activity to depth of 150mm Bq m^{-2}	
		Pb-210	Po-210	Pb-210	Po-210
1	ST 359 856	19.1 ± 2.2	25.2 ± 1.0	4500 ± 500	5900 ± 200
		-	22.9 ± 0.7	-	5300 ± 200
2	ST 387 860	27.2 ± 2.9	29.7 ± 1.1	5700 ± 600	6200 ± 200
3	ST 392 854	24.7 ± 2.8	24.5 ± 0.8	4600 ± 500	4500 ± 100
4	ST 395 831	23.8 ± 2.7	24.4 ± 0.8	3300 ± 400	3400 ± 100
5	ST 348 872	32.6 ± 3.4	32.9 ± 2.2	6700 ± 700	6700 ± 400
6	ST 366 873	33.8 ± 3.6	35.6 ± 1.0	8400 ± 900	8900 ± 300
7	ST 397 871	39.5 ± 4.2	40.4 ± 1.3	7800 ± 800	8000 ± 300
8	ST 391 889	42.5 ± 4.6	46.1 ± 1.1	10000 ± 1000	10400 ± 200

TABLE 14: MEASURED Pb-210 AND Po-210 CONCENTRATIONS IN SOIL FROM VICINITY OF LLANWERN

Location	Concentration, Bq kg^{-1}			
	Soil		Grass/herbage	
	Pb-210	Po-210	Pb-210	Po-210
Llanwern	< 30	< 10	57 ± 29	8 ± 3
Port Talbot	< 10	15 ± 8	26 ± 5	6 ± 1
Scunthorpe	23 ± 12	8 ± 2	< 10	< 5
Redcar	25 ± 4	33 ± 11	nd	nd
Background England / Wales	26 ± 14	24 ± 16	22 ± 14	14 ± 16

Note: nd means no data

TABLE 15: SUMMARY OF Pb-210 AND Po-210 CONCENTRATIONS IN SOIL AND HERBAGE FROM BACKGROUND SITES AND ENVIRONS OF SINTER PLANTS

	Bequerels per gram	
	Pb	Po
Solid materials		
Schedule 1 of RSA 93	0.74	0.37
Phosphatic Substances *etc* Exemption Order	14.8	14.8
Input materials - Iron ore	< 0.1	< 0.1
Coal ash	< 0.2	< 0.2
Waste materials - Sinter plant precipitator dust	0.7	2
Gas or vapour		
Schedule 1 of RSA 93	1.11×10^{-4}	2.22×10^{-4}
Waste - stack air	1.0×10^{-3}	2×10^{-3}

TABLE 16: COMPARISON OF CONCENTRATIONS IN MATERIALS AND WASTES FROM STEEL PLANTS WITH LEVELS SPECIFIED UNDER RSA93

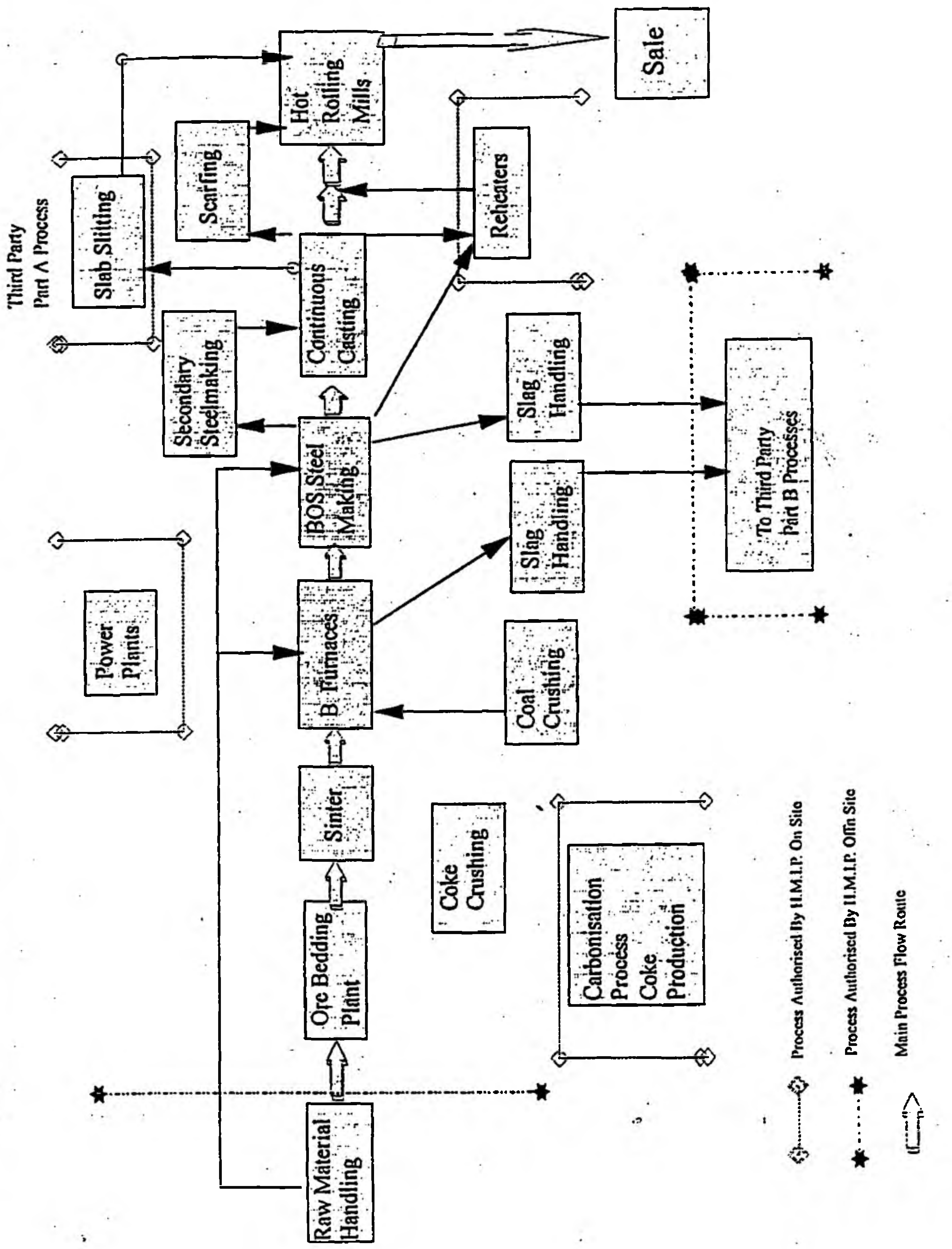

FIGURE 1: TYPICAL PROCESS FLOW DIAGRAM FOR AN INTEGRATED STEEL PRODUCTION SITE

ANNEX 1

RESULTS OF INITIAL ATMOSPHERIC DISPERSION AND DEPOSITION CALCULATIONS UNDERTAKEN BY BRITISH STEEL (Ref 1)

Note: These are the results used for the prupose of comparison with the independent calculations undertaken by CERC. The final radiological assessment by NRPB was based on different locations and hence slightly different dispersion and deposition data.

Terrain model	Met data	Emissions data	Residential site		Arable land	
			Annual aver. concentration Bq m^{-3}	Annual aver. deposit'n rate Bq m^{-2} s^{-1}	Annual aver. concentration Bq m^{-3}	Annual aver. deposit'n rate Bq m^{-2} s^{-1}
Scunthorpe						
Flat	Finningley	BS	4.3×10^{-9}	26×10^{-12}	4.3×10^{-9}	26×10^{-12}
Flat	Finningley	STM	4.6×10^{-9}	27×10^{-12}	4.6×10^{-9}	27×10^{-12}
Llanwern B						
Flat	Rhoose	BS	8.4×10^{-9}	356×10^{-12}	12.1×10^{-9}	347×10^{-12}
Flat	Rhoose	STM	5.2×10^{-9}	340×10^{-12}	8.0×10^{-9}	332×10^{-12}
Llanwern C						
Flat	Rhoose	BS	9.7×10^{-9}	198×10^{-12}	28.4×10^{-9}	329×10^{-12}
Flat	Rhoose	STM	10.1×10^{-9}	199×10^{-12}	29.2×10^{-9}	331×10^{-12}
Redcar						
Flat	Boulmer	BS	8.4×10^{-9}	48×10^{-12}	3.4×10^{-9}	24×10^{-12}
Flat	Boulmer	STM	7.2×10^{-9}	46×10^{-12}	2.9×10^{-9}	23×10^{-12}
Flat	Leeming	BS	12.9×10^{-9}	62×10^{-12}	4.2×10^{-9}	19×10^{-12}
Flat	Leeming	STM	11.6×10^{-9}	60×10^{-12}	3.9×10^{-9}	18×10^{-12}
Port Talbot						
Flat	Rhoose	BS	4.7×10^{-9}	196×10^{-12}	8.2×10^{-9}	155×10^{-12}
Flat	Rhoose	STM	3.6×10^{-9}	191×10^{-12}	6.8×10^{-9}	152×10^{-12}
Hilly	Rhoose-ISC	BS	11.3×10^{-9}	236×10^{-12}	2.5×10^{-9}	5×10^{-12}
Hilly	Rhoose-ISC	STM	10.0×10^{-9}	232×10^{-12}	2.5×10^{-9}	5×10^{-12}

Notes: 1. All results are for a release rate of 1 Bq s^{-1}.
2. Rhoose-ISC met data is a sub-set of data derived from analysis of frequency of occurrence of combinations of Pasquill stability class, wind speed and wind direction for Rhoose, using the suggested parameters in the ADMS 2 User Guide to convert stability classes into the input terms required for ADMS.