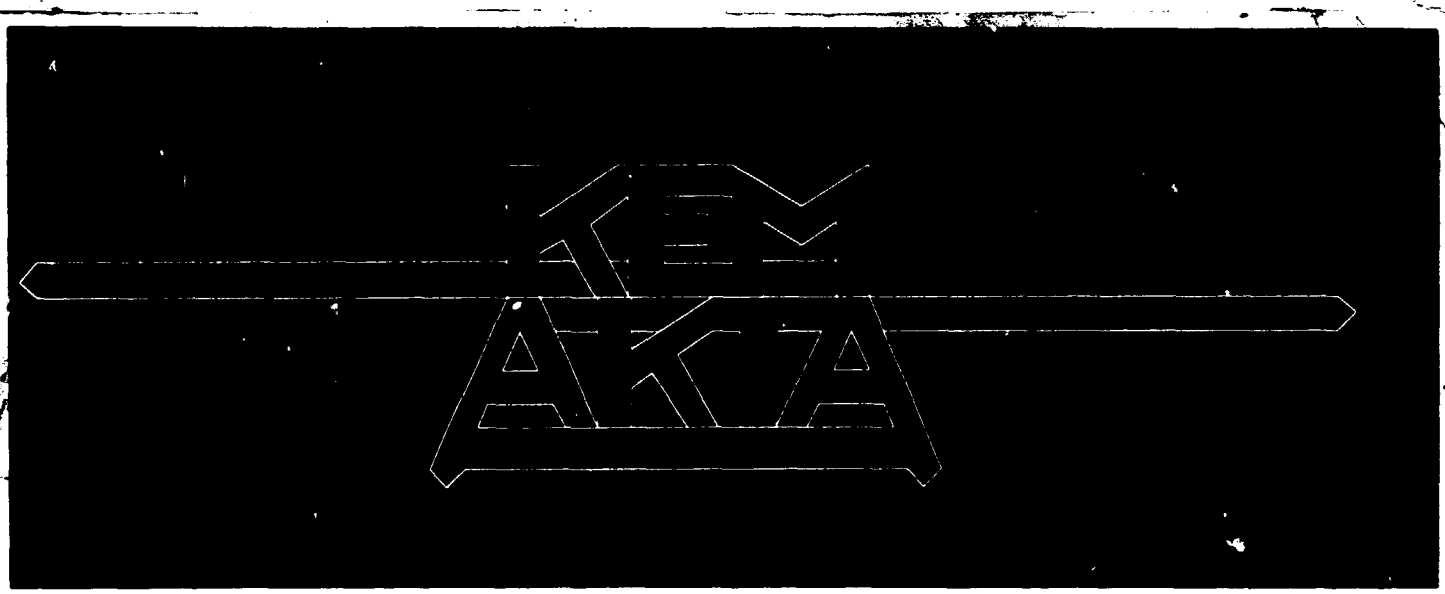

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Basis for criteria for exemption of decommissioning waste: Reprocessing of dust from recycling of steel

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SUMMARY

This study is a part of a larger study with the purpose to provide the authority concerned, the Swedish Radiation Protection Institute (SSI), with technical background material needed for future decisions concerning exemption levels for recycling and disposal of material originating from decommissioned nuclear power reactors.

The dismantling of nuclear power reactors will give rise to large amounts of steel scrap with a very low activity concentration. It is of interest to exempt this material from regulatory control in order to make recycling possible. During the melting of steel scrap dust will be formed which is collected in the off-gas cleaning system of the furnace. Radionuclides may be enriched in this dust, and thereby obtain a higher activity concentration than the melted scrap. Presently, there is a strong interest to reprocess these dusts with the objectives to recover valuable metals and to reduce the amount of waste harmful to the environment. During the reprocessing of dusts collected from the melting process a further redistribution and reconcentration of radionuclides may occur.

In this report the treatment of dust from steel melting is described, the potential reconcentration of radionuclides is analyzed, and the potential radiological consequences are estimated. The study has focussed on the reprocessing of dust with the plasma method used at ScanArc in Sweden, and with the Waelz process used in, for example Spain and Germany.

Various factors as economical, political and future developments of dust treatment and steel processes will determine the amounts of dusts produced and also to what degree dust will be reprocessed in the future.

List of contents

1 INTRODUCTION

1.1 Background

The technical and economic lifetime of nuclear power reactors is limited. After the reactor is taken out of operation, the decommissioning process will commence. This may comprise several stages involving sealing, surveillance, decontamination and finally, dismantling and removal of remaining materials. Several alternative strategies for decommissioning exist. The time between shutdown of the nuclear power reactor and dismantling and total removal of the plant will be determined by e.g. legislative, health, technical and economical aspects.

The dismantling of nuclear power plants will result in wastes with varying activity concentration. Some systems, e.g. the reactor tank and its internal components, and parts of the biological shield will have a high concentration of activity and have to be treated as radioactive waste. However, the dismantling of nuclear power plants will give rise to large amounts of material with a very low activity concentration, including steel and other metals with a significant scrap value. It is of interest to exempt these materials from regulatory control in order to make recycling possible.

In a previous study, the radiological consequences of both disposal and recycling of large quantities of exempted decommissioning waste were analyzed [*Elert et al., 1991*]. As a part of the study, the option of melting steel scrap was studied. Models were developed for estimating the dose from storage, pretreatment, and melting of steel scrap, and the dose from manufacturing and final use of products made of the steel scrap. In addition the doses arising from recycling and disposal of the various byproducts from steel production were studied.

In the previous study, the redistribution of radionuclides during the melting and possible reconcentration of radionuclides in byproducts were identified as potentially important areas where there was a need for further studies. It was noted that reprocessing of dusts collected in the off-gases from the furnaces used for steel melting is becoming more frequent and that the possible consequences of this on the redistribution of radionuclides have so far not been studied.

1.2 Purpose

This study is a part of a larger study with the purpose of providing the authority concerned, the Swedish Radiation Protection Institute (SSI), with the technical background material needed for future decisions concerning exemption levels of material for recycling and disposal. The purpose of the present study is to provide complementary information concerning the treatment of dust from steel melting and examine the potential radiological consequences of the reprocessing of dust.

1.3 Scope and methodology

This study includes a description of the present day situation in Sweden concerning the treatment of dust from steel melting, the amounts produced and to what degree reprocessing occurs and by which methods. A short review is also made of the situation in Europe and in the rest of the world.

An analysis is made of the most frequently used reprocessing methods, identifying their potential for redistribution and reconcentration of specific radionuclides. The methods studied are the plasma method used by ScanDust in Sweden and the Waelz-method used in Europe.

The various factors influencing the future development of dust treatment and reprocessing are discussed and the assessment of future development made by industry and authorities are presented.

Finally, the previously developed models for estimating the radiological consequences are applied on a few cases to illustrate the magnitude of the doses which can result from reprocessing of dust.

2 DUST FORMATION FROM SCRAP MELTING

2.1 Scrap melting at the steelworks

Scrap steel is the primary source for many of the Swedish steelworks. Every year roughly 800 000 tonnes of scrap is collected and melted. In addition 75 000 - 100 000 tonnes of scrap metal is imported, mostly alloyed and stainless steel scrap. However, these values vary depending on demand of steel and on metal prices.

The scrap is the main raw material for steel production in electrical arc furnaces, but scrap metal is also added in the production of steel directly from ore. Roughly 10% scrap metal is added for cooling during the conversion of the raw iron to steel.

The collection and pretreatment of scrap is to a large degree performed by specialized companies, but some pretreatment is also made at the steelworks. The pretreatment includes sorting according to size and content of alloy metals, and preparation of the scrap so that it can be directly charged into the furnaces.

2.1.1 Dust formation in scrap based steelworks

During the scrap melting dust will be released, either mechanically due to the gas flow in the furnace or chemically due to volatilization. The dust consists mainly of iron oxides, manganese oxide, silicates and lime. It will also contain other metals originating from the incoming scrap, e.g. Cr, Ni, Pb, Zn, Hg, etc. The composition of the dust may vary considerably depending on the scrap being melted, contamination of the scrap, and the slag forming substances added into the melt, e.g. CaO or CaF_2.

An arc furnace produces 10 - 15 kg dust per tonnes of steel produced. In 1990, a total of roughly 28 000 tonnes of dust was produced in Sweden, whereof 9000 tonnes contained more than 20% zinc, and 8000 tonnes contained nickel and chromium [*Lindblad, 1991*]. The dust with high zinc content originate from melting of galvanized scrap and Ni/Cr containing dust originate from the melting of stainless steel scrap. Most of the dust produced is collected in filters. Only 0.03-0.6 kg dust per tonnes of steel is released to the atmosphere.

2.1.2 Dust formation in ore based steelworks

In the ore based steelworks coke and iron ore are inserted into a blast furnace producing raw iron. The raw iron is converted to steel by reducing the carbon content with oxygen in a LD-converter, i.e. a standing furnace where the oxygen is blown from above towards the surface of the melt. During the conversion scrap metal is used for cooling. Roughly 10% of the charged amount consists of scrap from the internal scrap recycling or from external sources. The added scrap should be non-alloyed with a low carbon content. During the LD-conversion 25 kg dust is formed per tonnes of steel. The primary release of dust from the LD-converter is separated in a scrubber while the secondary release from

the converter building is collected in textile filters. Svenskt Stål AB (SSAB) produces annually around 15 000 tonnes of dust at the steelworks in Oxelösund and around 40 000 tonnes at the steelworks in Luleå. The dust consists mainly of oxides of iron, calcium, magnesium, and silica. The dust may contain 0.5 - 1 % of zinc.

2.2 Scrap metal from decommissioning

The decommissioning of a nuclear power reactor will give rise to waste of varying activity concentration and radionuclide distribution. In the present study we are concerned with steel components with a low activity concentration.

The materials in a nuclear power reactor can become radioactive either by the neutron flux from the reactor core or by surface contamination of radionuclides present in the reactor cooling water, in the steam, or in the water of the secondary systems. The major amount of steel waste in question for exemption is likely to be surface contaminated pipes, valves, pumps, or other components. So far most decommissioning studies have focussed on the parts of the reactor with high activity concentration. Thus, there are only general information available on the amounts of waste with a low activity concentration. In this study it is assumed that 5000 tonnes of steel waste per reactor may be in question for exemption. This is the same amount as in the previous study [*Elert et al., 1992*] and is based on decommissioning studies performed in Sweden and in the United States [*SKB, 1986; Smith et al., 1978; Oak et al., 1980*].

The radionuclides in the surface contamination are mainly activated corrosion products (e.g. ^{54}Mn, ^{55}Fe, ^{60}Co), but fission products (e.g. ^{90}Sr and ^{137}Cs) and actinides (plutonium and americium) may also be present due to leakage from failed fuel rods. Mostly, it is the inner surfaces of the components that are contaminated. The level of activity and the radionuclide composition may vary substantially between different systems in a reactor, but also between different reactors depending on type, size and on events that has occurred during operation of the reactor, e.g. degree of fuel leakage or incidents during operation. The components may also undergo various types of decontamination before exemption.

Table 2.1 gives a number of typical compositions for surface contaminated steel waste in relative units. The first column gives average values for surface contamination 5 years after reactor shutdown. The values are based on experimental and theoretical data from a number of European PWRs [*Smith et al., 1985*]. The second column gives the estimated radionuclide composition of surface contamination of the Oskarshamn 2 reactor. The composition is based on the calculated total inventory of activation products, fission products and actinides assuming minor fuel leakage [*Lundgren, 1991*]. The third column is from the same reference, but is based on a scenario with more severe fuel leakage every tenth year. In both cases the inventory given is for one year after reactor shutdown.

2.2.1 Dust formation from melting of exempted scrap

The melting of 5000 tonnes of exempted steel waste from a nuclear power reactor in an electric arc furnace would correspond to the formation of 50 tonnes of dust assuming a dust formation of 10 kg per tonnes of scrap. If scrap metal was used for cooling in the LD-converter of an ore based steelworks roughly 125 tonnes of dust would be formed.

2.3 Dust handling and processing options

2.3.1 Scrap based steelworks

The dust recovered from the arc furnaces has a low iron content and requires large amounts of energy to remelt. Therefore, it has not been economical to recycle the dust into the furnaces. Recycling may also result in a high content of zinc and lead in the furnace which can give production problems. The dust has therefore to a large extent been disposed of as waste. However, the dust has a high content of heavy metals and may therefore constitute an environmental problem. This together with an economical interest to recover valuable metals such as chromium and nickel has lead to an increased interest in reprocessing. The dust from some steelworks has a very high zinc content and is also reprocessed.

The dust from the arc furnace is collected in textile filters which are automatically emptied into silos or special containers. From there the dust is sent to a temporary storage awaiting shipment to the reprocessing plant, or to a disposal site. The dust is watered in order to avoid aerosolization during the handling. The dust sent for reprocessing at ScanDust is collected in large bags, so called "Big Bags". The reprocessing of dust will be treated further in Chapter 3.

At some steelworks large amounts of dust are stored awaiting possible future reprocessing. The dust is placed on hard made ground and covered for example by plastic sheets.

The design and structure of permanent disposal sites varies. Newer sites have specially designed covers and systems for treatment of leach water. These disposal sites are also constructed in such a way that the dust could be recovered for future reprocessing.

The reprocessing option chosen for the dust varies between different steelworks depending on the availability of suitable reprocessing methods, suitable deposits, and the requirements put up by the authorities. In Table 2.2 a summary of the present situation in Sweden is given.

2.3.2 Ore based steelworks

The dust from the LD-conversion in ore based steelworks can either be deposited (SSAB, Luleå) or sintered and recycled in the blast furnace (SSAB, Oxelösund). The dust has normally a low content of heavy metals and is thus not considered as a major environmental problem.

2.4 Distribution of radionuclides in the melting process

The melting of exempted waste will lead to the introduction of a number of radioactive elements in the steel production process. During the steel production these elements will be distributed between the steel and the various by-products. This section gives an overview of the processes that will affect the distribution of radionuclides during the melting process. The focus is on processes that can lead to a reconcentration of

radionuclides. Rough estimates of the potential reconcentration has been made based on the amounts in the different material streams and waste streams. These are presented as potential reconcentration factors, i.e. the reconcentration which will be achieved if all of a radionuclide is transferred from one material stream to another. These potential reconcentration factors are based on the melting of 5000 tonnes of exempted scrap metal from a decommissioned nuclear power reactor. Thus, no credit has been taken to any dilution with scrap metal from other sources.

2.4.1 Scrap based steelworks

Radionuclides in the melted metal scrap will during the melting be distributed between the slag, the steel and the dust. The distribution of radionuclides during melting of scrap in electrical furnaces has not been extensively studied. The distribution will depend on the chemical properties of the radionuclides, the metallurgical composition of the scrap, the various slag forming substances added, and the melting method used. Some information on the radionuclide distribution could be obtained from the behavior of elements normally present in melt. In some cases the radionuclides are isotopes of the same elements.

Chemical properties of importance for the radionuclide distribution are the boiling point of the metal, how easily the element is reduced, the boiling point of the oxide, and the vapor pressure. The distribution can be estimated using thermodynamic equilibrium models, but difficulties are introduced because of the lack of data for many substances as well as due to the fact that the reactions may not be in equilibrium in an electrical arc furnace. A summary of some of the element data relevant for the radionuclides is given in Table 2.3.

More volatile radionuclides such as zinc and cesium are enriched in the dust, while the ferric metals (Fe, Ni, Mn) will tend to remain in the steel. However, a small fraction of the ferric metals is mechanically removed during the melting, but they are not likely to be enriched in the dust. Radionuclides that are difficult to reduce will remain as oxides and will be enriched in the slag. The slag from an electrical arc furnace is highly basic, i.e. with a high ratio between lime and silica.

There is only limited information available on the redistribution of radionuclides in connection with scrap melting. Measurements of the radionuclide distribution have been made in connection to scrap metal from a decommissioned heat exchanger at the induction furnace at the nuclear research institute in Studsvik [*Hernborg and Andersson, 1988*], see Table 2.4. However, it is difficult to draw definite conclusions from these results since the melting is performed in a different type of furnace compared to that used at larger steelworks. In an induction furnace a more complete mixing of the melt is achieved, and the amount of dust produced is considerably smaller than in an electric arc furnace. Other studies of the radiological consequences of melting steel scrap from decommissioned nuclear power plants have used radionuclide distributions based on a combination of assumed and measured values [*CEC, 1988; Chapuis et al., 1987*]. Due to the large uncertainty in the distribution, conservative estimates have been strived for. Thus, the sum of the percentage of the incoming activity ending up in the ingot, the slag, and the dust has in many cases been assumed to exceed 100 percent. The radionuclide distribution assumed in this study is given in Table 2.5.

Radionuclides preferentially transferred to the dust may be highly concentrated. Since the amount of dust corresponds to a 1/100 of the amount of initial scrap, a radionuclide completely transferred to the dust would be concentrated by a factor of 100.

2.4.2 Ore based steelworks

In ore based steel production the iron ore is reduced with coke and melted in a blast furnace. The raw iron is converted to steel by reducing the carbon content with oxygen in a LD-converter. During the LD-conversion scrap metal is added for cooling. Since only between 10 and 20% of the charged amount is scrap metal, a dilution of the activity with a factor of 5 - 10 will occur. The melted steel is mixed by the strong convective currents in the converter so a relatively homogeneous product can be expected. The by-products from the LD-conversion are slag and dust. At SSAB Oxelösund both slag and dust are recycled into the blast-furnace, at SSAB Luleå only the LD-slag.

Below, a short description is given of the recycling of dust at SSAB Oxelösund. The dust coming directly from the converter is collected in a two step venturi scrubber, the process water is treated with flocculating agents and the sludges are dewatered in a filter press. Roughly one tonnes of sludge is formed per 50 tonnes of steel produced in the LD-converter. This could give a potential reconcentration factor of 50. The LD-sludges are sintered before recycling into the blast-furnace and will there be mixed with the incoming ore. Roughly one tonnes of recycled LD-sludge is added per 40 tonnes of ore. Thus a considerable dilution will occur. During the sintering more volatile elements, such as zinc and lead, will be removed and may be concentrated in the flue gases. The flue gases are cleaned in a cyclone filter and the collected dust is recycled in the sinter works. The secondary release from the LD-converter, i.e. dust released to the converter building is collected in a dry electro filter and disposed.

Volatile radionuclides are likely to vaporize during the conversion and will be collected in the venturi scrubber. The sludge from the scrubber consists mainly of iron and iron oxides, (80%), but contains also lime and oxides of manganese, magnesium, vanadium and titanium. The zinc content is normally less than 1 percent. Soluble radionuclides such as cesium will probably not be precipitated with the sludges, but will be released with the waste water. Annually 18 000 m^3 of waste water is released from the cleaning system for the LD-converter. This water is later mixed with about 300 million m^3 of waste water from other parts of the steelwork. It is thus likely that the concentrations of cesium in the waste water will be very low.

Less soluble radionuclides, such as zinc, will precipitate with the sludges. This would give a potential reconcentration of 10 in the LD-sludges based on the addition of 20% metal scrap during the conversion.

Table 2.1 Typical compositions for surface contaminated steel wastes in relative units

Nuclide	Inventory 1	Inventory 2	Inventory 3
Mn-54		2.64e-02	2.21e-02
Fe-55	6.67e-02	5.77e-01	4.81e-01
Co-58		6.97e-03	5.82e-03
Co-60	6.67e-01	3.37e-01	2.81e-01
Ni-59	6.67e-05	2.40e-04	2.01e-04
Ni-63	1.33e-02	3.85e-02	3.21e-02
Zn-65		3.12e-03	2.61e-03
Sr-90	3.33e-02	4.09e-03	6.62e-02
Zr-93	6.67e-07	5.53e-11	1.00e-09
Nb-94	6.67e-06		
Tc-99	6.67e-06		
Ru-106		3.37e-06	3.81e-05
Sb-125	6.67e-02		
Cs-134	2.67e-02	4.09e-05	1.04e-05
Cs-135	2.00e-07	1.39e-07	1.32e-06
Cs-137	6.67e-02	7.21e-03	1.08e-01
Ce-144		3.37e-05	4.41e-04
Pm-147	6.67e-02		
Pu-238	5.00e-04	1.32e-08	3.61e-07
Pu-239	6.00e-05	2.64e-09	7.02e-08
Pu-240	8.00e-05	3.12e-09	8.22e-08
Pu-241	1.40e-02	7.93e-07	2.21e-05
Am-241	1.67e-04	9.37e-10	2.61e-08
Cm-242		3.12e-08	9.63e-07
Cm-244	2.33e-04	8.17e-09	2.21e-07
TOTAL	1.00e+00	1.00e+00	1.00e+00

Inventory 1: Surface contamination 5 years after shutdown, Smith et al., 1985
Inventory 2: Surface contamination. Small fuel leakage. 1 year after shutdown, Lundgren, 1991
Inventory 3: Surface contamination. Large fuel leakage. 1 year after shutdown, Lundgren, 1991

Table 2.2 Dust generation and dust handling at Swedish electro steelworks

Type	Name	Location	Amount (tonnes)	Dust handling
Commercial steel	Fundia,	Smedjebacken	7400	Storage for future reprocessing
Low alloy	Ovako	Hofors	5200	Disposal/Reprocessing
	Ovako	Hällefors (closed)	2500	Disposal
	Boxholms	Björneborg	500	Disposal
	IPASCO	Lesjöfors	50	Disposal
Stainless	Avesta	Avesta	2400	Disposal/ScanDust
	Avesta	Degerfors	4000	ScanDust
	Sandvik	Sandviken	2000	Storage for future reprocessing
Tool steel	Uddeholm	Hagfors	2000	Disposal
Speed steel	Kloster	Söderfors	800	Disposal
Steel powder	Höganäs Kanthal	Bohus (now moved to Halmstad)	2000	Storage for possible reprocessing

Table 2.3 Chemical properties of elements

Element	Boiling point element [C]	Boiling point oxide [C]	Temp. giving vapor press. of element of 1 mm Hg [C]	10 mmHg [C]	100 mmHg [C]	Solubility in water of oxide	
Al	2467	2980	1540	1780	2080	insol	
Am	2607						
Ca	1484	2850	800	970	1200	slight	
Cd	765	1559 sub	393	486	610	insol	
Ce	3257					insol	
Co	2870		1910	2170	2500	insol	
Cr	2672	4000	1610	1840	2140	insol	ox soluble
Cs	669	400 dec		373	513	soluble	
Fe	2750	1565	1780	2040	2370	insol	
K	760				590	soluble	
Mn	1962			1510	1810	insol	
Na	883	1275 sub	440	546	700	soluble	
Nb	4742					insol	ox soluble
Ni	2732		1800	2090	2370	insol	
Pb	1740	1470	970	1160	1420		
Pm	2460?						
Pu	3232						
Ru	3900						
Sb	1750	1550 sub		980	1280	very slight	
Se	685	317 sub	-	429	547	soluble	
Sr	1384	3000	740	900	1100	slight	
Tc	4877	311					
V	3380	1750 dec	2290	2570	2950	slight	
Zn	907		-	590	730	slight	
Zr	4377	5000				insol	

dec= decomposes sub= sublimes ox= oxidizing conditions

Table 2.4 Distribution of radionuclides during melting

Element	Measured Hemborg & Andersson, 1988			Assumed in consequence study CEC, 1988			Assumed in consequence study Chapuis et al., 1987		
	Steel	Slag	Dust	Steel	Slag	Dust	Steel	Slag	Dust
Mn	84	15.8	0.2	100	1	10	100	1	0.5
Fe				100	1	0.1	100	1	0.5
Co	99.6	0.3	0.07	100	1	0.1	100	1	0.5
Ni				100	1	0.1	100	1	0.5
Zn	90.1	0.5	9.4				1	1	100
Sr				10	100	10	100	100	10
Zr									
Nb							100	10	1
Tc									
Ru							10	100	100
Sb	0	0	100				100	1	100
Cs	0	~80	~30	10	1	100	1	100	100
Eu							100	100	0.5
Np, Pu, Am, Cm				10	100	1	10	100	0.5
Byproducts	5700 kg ingot 73 kg slag 3 kg dust			10 kg of dust / 1000 t steel 100 kg slag/1000 t steel			Amounts of slag and dust not given		

Table 2.5 Distribution of radionuclides during melting, values used in calculations

Element	Distribution of elements (Percent of amount in scrap)		
	Steel	Slag	Dust
Mn	100	10	10
Fe	100	1	1
Co	100	1	0.5
Ni	100	1	0.5
Zn	100	1	100
Sr	100	100	10
Zr	100	1	0.5
Nb	100	10	1
Tc	100	100	100
Ru	10	100	100
Sb	100	1	100
Cs	10	100	100
Eu	100	100	1
Np, Pu, Am, Cm	10	100	1

3 REPROCESSING OF DUST

The dust generated from Swedish steelworks can be reprocessed either in Sweden or exported to other countries for reprocessing. At present, reprocessing is not performed on all dust recovered at the steelworks. Large amounts of dust are stored at the steelworks or disposed of in such away that future reprocessing should be possibly. However, there is an increased interest by the steelworks for recycling of dust and other residues in their own processes to limit the amounts which must be sent for reprocessing or disposal.

The composition of the dust determines which process can be used for reprocessing. Dust from alloyed steelworks with low zinc content can be reprocessed in Sweden at ScanDust by a process based on plasma technology. Dust from other steelworks with high zinc content can be sent for reprocessing by a pyro metallurgic process (Waelz process) in Germany or Spain at facilities operated by Berzelius. Presently, the possibility of building a reprocessing facility for dusts with a high zinc content in Sweden is being investigated. At Boliden Mineral (Rönnskärsverken) slag from manufacturing of copper and lead is reprocessed by slag fuming for recovery of zinc and lead. The possibility exists to also reprocess external dust from the steelworks.

Firstly, in Section 3.1. to 3.2 the possibilities which exist today to reprocess dust in Sweden and other countries are discussed. Here also information is given about the reprocessing processes as a basis for the estimations on radiological consequences from dust generating from exempted waste presented in Chapter 4. In Section 3.3 the potential distribution of radionuclides in products from reprocessing is commented upon. Finally, in Section 3.4 factors which will influence future reprocessing of dust are discussed.

3.1 Reprocessing of dust in Sweden

3.1.1 ScanDust

In southern Sweden a facility (ScanDust, Landskrona) has been built for reprocessing of dust from air cleaning systems at steelworks for alloyed steel and thereby recovering potential valuable metals as Ni, Mo, Cr, Mn and Fe.

In 1990, around 30 000 tonnes of dust were reprocessed, corresponding to approximately 6 tonnes per hour. The facility has a capacity of 9 tonnes of dust per hour, so the productivity was 65% in 1990. Around 40 to 60% of the dust is recovered as metal and sent back to the steelworks. The metal recovery is dependent on the source for the dust. Of the incoming dust for reprocessing 1990 less than 5 000 tonnes originated from Swedish steelworks and the rest came from steelworks in Germany, Finland and France [*ScanDust, 1990*] .

Description of the plasma furnace process

Figure 3.1 gives a schematic description of the material flow at the ScanDust facility. The raw material is transported to the facility in "Big Bags" containing approximately 1.5

tonnes. Most of the dust is prestored in a silo system before reprocessing. The dust is analyzed and mixed with small amounts of lime, sand and dry coal. Thereafter, the dried mixture is pneumatically transported and injected into the plasma furnace. In the furnace the energy is supplied by three plasma generator with a maximum effect of 3 X 6 MW. The temperature of the plasma is around 5000°C.

In the furnace, the main part of the metals are reduced. The non-volatile metals form iron based alloys which are returned to the steelworks for melting. The volatile metals, especially Zn and Pb will be transported away with the process gas at a temperature of approximately 1150°C. The process gas consists of about 85% CO and 10% H_2. The zinc and lead can be recovered in a special zinc condenser, where the process gas is sprayed with liquid lead. The zinc condenser is only used during the reprocessing of dust with a high zinc content, more than 6%. The process gas is cooled and cleaned in a venturi scrubber system. If the zinc condenser is not used, the zinc will be separated in the venturi scrubber. The process gas is thereafter partly recycled and the remainder is treated in a selenium filter for collection of mercury. The present wet gas cleaning system is a bottle-neck in the production and ScanDust is evaluating the possibilities of replacing the system with a dry gas cleaning system [*Johansson and Löfgren, 1990*].

The main waste stream from the process is the slag which amounts to 6000 - 7000 tonnes per year based on the reprocessing of 30 000 tonnes of dust. The waste is presently disposed of at the facility under controlled conditions. Sludges from the venturi scrubber system are separated from the process water and dewatered. In 1990, 6500 tonnes of sludges were collected and exported to Berzelius for further reprocessing of zinc. The process water is cleaned from cyanides by heating, a pH lowering and airing. Further, hexavalent chromium is reduced with sodium bisulphite. After that the pH is increased by adding NaOH and the metals are precipitated as hydroxides. The hydroxide sludge is recirculated to the plasma oven. In the next step fluorine is precipitated as CaF_2 by adding $CaCl_2$. The fluoride sludges are temporarily stored waiting for final disposal. The main constituents of the iron based alloy, the slag and the sludges are given in Table 3.1.

3.1.2 Rönnskärsverken

In all melting processes for production of copper and lead, slags with a varying content of lead, copper and zinc are formed. At Rönnskärsverken these slags are treated in a special process (slag fuming) for recovery of zinc and lead. The fuming furnace is charged with liquid slags, but has also the possibility to handle cold slags, external dust and ashes. The production is presently approximately 45 000 tonnes of zinc clinker per year, but may vary depending on the metal content in the supplied slags [*Rönnskär, 1990*]. Small amounts of dusts from electrical arc furnaces have been processed successfully, but no commercial reprocessing is presently performed.

The fuming process is a discontinuous process. The recovery is based on a reduction of the metals and the reduction is performed by coal powder blown into the liquid slag in the bottom of the furnace.

Metallic zinc and lead are driven of as gas, also containing nitrogen, carbon monoxide and unburned coal. Above the slag additional air is supplied into the gas. Hereby, the carbon monoxide and the coal are reduced and the metal gases, mainly zinc, are oxidized to metal

oxides. The metal oxides follow the gas stream to a conditioning tower where the gas is cooled from 400°C to approximately 100°C by spraying with water. The mixed oxides are thereafter separated from the gas in the gas cleaning system by electro filters. Finally, the mixed oxides are transported by a closed transport system to an intermediate storage at the clinker work. At the clinker work chlorine, fluorine and part of the lead is driven off in a furnace and a zinc clinker is produced. The zinc clinker can be sent to Norway for electrolytic recovery of zinc.

The fumed slag is treated in a separate furnace for recovery of copper in the form of copper matte and speiss. Hereafter the slag from the furnace is granulated and pumped to the slag disposal area. The copper can be supplied to the converters at the copper work or sold.

3.2 Reprocessing of dust in other countries

In this section some examples are given of reprocessing processes for dust in other countries.

3.2.1 Reprocessing of dust in Germany and Spain

The reprocessing of dust by the Waelz process is presently performed at the Berzelius works in Duisburg, Germany and in Bilbao, Spain. The recovery of zinc by volatilization in a rotary kiln was patented in 1910. In the original process various types of raw materials were considered e.g. ores, tailings, residues and slags [*Mac Rae, 1985*].

Description of the Waelz process

A schematic description of the flow sheet of the Waelz process at the Berzelius plant in Duisburg is given in Figure 3.2. The recovery of zinc and lead from steelmaking dust is based on reduction, volatilization and reoxidation [*Maczek and Kola , 1980*].

The raw material is discharged into underground bins and supplied from the bins by belt conveyors to one half of the divided feed hopper. In the other half of the feed hopper the coke breeze required as fuel and reducing agent is supplied. The metal bearing mixture and the coke breeze are simultaneously fed to the rotary kiln. The formed metal vapors at the charge are oxidized in the kiln to obtain zinc and lead oxide. The mixed oxides are transported with the flue gas leaving the kiln at a temperature of approximately 900°C and are collected in the gas cleaning system consisting of cooling tower, gas cooler and electrostatic precipitater. The mixed oxide (Waelz oxide) is after precipitation lead to a pelleting plant or used directly in the sintering plant. From the kiln, discharge excess coke breeze is recovered for reuse after separation of the magnetic fraction. The remaining coarse slag as well as the magnetic fraction are dumped or discharged for further reprocessing.

At normal operation during the eighties 50 000 to 55 000 tonnes of electric furnace dust were reprocessed, giving 20 400 to 22 400 tonnes of Waelz oxide and a slag production

of 37 500 to 41 300 tonnes. In Table 3.2 an analyses of the dust, the Waelz oxide and the slag at normal operation is given [*Maczek and Kola, 1980*].

3.2.2 Reprocessing of dust in Japan

In Japan several plants based on the Waelz process for de-zincing of iron and steel making dust have been in operation, mainly for recovery of the iron content and recycling to electric arc furnaces or blast furnaces. These plants have been replaced by plants based on the less expensive wet separation techniques to remove the zinc from the blast furnace dust. A modification of the Waelz process has been developed to process steel making dusts.

Description of the "HTR" process

The "HTR" process is based on selective reduction of incoming metals. The modified process consumes less carbon than the Waelz process. A schematic flow sheet of the "HTR" process is presented in Figure 3.3. The zinc oxides are reduced, vaporized and oxidized back to zinc oxides. By controlling the temperature and the reducing gas potential the metallization of iron is less than 5% and the zinc recovery about 90%. The crude zinc oxides are sold to zinc refiners and the residues containing about 2% of zinc is sold to the cement industry or used as landfill [*Mac Rae, 1985*].

3.2.3 Reprocessing of dust in USA

St. Joe Mineral electro thermic smelter in Monaca, Pennsylvania processes zinc ore concentrates but can also process dusts that have been upgraded to contain more than 50% zinc oxide. The St. Joe facility were in 1985 the only zinc based smelter in USA and Canada [*Mac Rae, 1985*].

Description of the St. Joe smelter

A schematic description of the zinc metal furnace at St. Joe is given in Figure 3.4. The energy is being supplied at the bottom and the top of the smelter. The zinc oxides are reduced and vaporized by the gas generated by the added coke. The vaporized zinc is condensed by drawing the furnace gas through a cooled zinc melt and the zinc product is of Prime Western grade. The solid residues produced in the process are recycled-coke, spent-slag and the byproduct ferrosilicon.

3.3 Distribution of radionuclides in the dust reprocessing

Most methods for reprocessing of steelwork dusts are based on heating and reduction of the dust. In the ScanDust process the reduced melted metals are recovered. Byproducts are the slag and the sludges from the cleaning of the process gas. In the Waelz process the evaporated metals are later oxidized and a mixed oxide of zinc and lead is recovered. The main byproduct is a slag of non-volatile oxides.

Potential distribution of radionuclides ScanDust process

The plasma furnace will act like a distillation column with recycling, separating the more volatile metals. Radionuclides enriched in the dust at the steelworks due to evaporation in the arc furnace will again be vaporized and released by the process gases. These radionuclides will end up in various residues during the cleaning of the process gases. With a wet cleaning system, e.g. a venturi scrubber, the enrichment of radionuclides in the various residues will depend on the solubility of the radionuclides. Insoluble radionuclides will end up in the sludges or precipitates, while soluble radionuclides will be released with the process water. If dry cleaning systems are used, e.g. textile filters, only one residue will be formed. The residues from both wet and dry gas cleaning systems are either recycled to the process or further reprocessed.

In the plasma furnace, radionuclides present in the dust due to mechanical removal in the arc furnace will be transferred to the recycled metal or to the slag. For radionuclides transferred to the metal, the potential reconcentration may be a factor of 2. The metal will be returned to the steelworks, where it is mixed with scrap from other sources for remelting. Consequently, there will not be any net reconcentration for the total process. Radionuclides completely transferred to the slag will have a potential reconcentration factor of roughly 5. However, these radionuclides are those which are very difficult to reduce and will remain in stable oxide forms. These radionuclides will not have been enriched in the melting at the steelworks.

Table 3.3 gives a rough estimation of the distribution of radionuclides between the different products at the ScanDust facility. The values are based on the measured composition of elements given in Table 3.1 and on the distribution assumed during the melting in the arc furnace. Conservative values have been chosen for radionuclides where little information is available, e.g. technetium and ruthenium. Also the information of the composition of the hydroxide and the fluoride sludges was limited. The distribution was set to 1 percent for all radionuclides in these materials.

Potential distribution of radionuclides in the Waelz process

In the Waelz process the main products are the Waelz oxides and the slags. The potential reconcentration of radionuclides transferred to the Waelz oxide is approximately a factor 2 and for the slag less than a factor 2. In the Waelz oxide about 95% of zinc and 90% of the lead is recovered. The potential for reconcentration of radionuclides is thus less than for example in the ScanDust process.

In the rotary kiln all compounds with sufficiently high vapor pressure will be volatilized. The temperature in the kiln is around 1200°C. Chlorine and fluorine are volatilized almost completely and more than 50% of the potassium and sodium are transferred to the oxides. Tin and cadmium are volatilized to about 50% and almost 100% respectively. It is likely that also a considerable amount of the cesium will be transferred to the oxides, since it is more volatile than both sodium and potassium. Other compounds found in the Waelz oxides are mainly incorporated by mechanical carry over of slag forming agents as e.g. SiO_2, Al_2O_3, CaO and FeO, the carry over is estimated to be about 5%. Since the metal vapors are oxidized in the kiln it is probable that the radionuclides forming less volatile oxides will be transferred to the slag. This could for example be the case for strontium.

The iron and almost all of the incoming copper and arsenic is found in the slag. In Table 3.2 the distribution of elements in the Waelz oxide and the slag after reprocessing of electric furnace dust is given. This information can be used as an indication of the distribution of radionuclides in the reprocessing of dusts.

All materials recovered from the processes gases will contain zinc and lead and will be further reprocessed. However, very volatile elements, such as mercury, may be discharged through the stack.

Other processes

The slag fuming processes at Rönnskärsverken is similar to the Waelz-processes in that the metal vapors are oxidized and that the material recovered from the processes gases will be reprocessed. Dusts from electrical steelworks will also be mixed with large amounts from other origin. The potential for an enrichment of radionuclides is thereby very small.

3.4 Factors influencing future reprocessing of dust

There are many factors which will influence to what extent and how dust is reprocessed in the near future. Naturally economical factors will play a major role but also technical changes, environmental concern and legislative aspects as export permits will be of importance for future reprocessing or disposal of dust.

Economical factors

The economy in reprocessing will depend on the cost for reprocessing, the metal prices and the costs for disposal. At the present level of metal prices reprocessing is not economical unless large investments in new disposal sites and expensive conditioning are required.

The possibility exist that the production of waste which must be disposed of in future will be charged with environmental fees. This system is presently in practice for the release of gases such as NO_x and CO_2 to the environment. Such fees could also change the economics for reprocessing.

Technical changes

At present there is a shortage in capacity for reprocessing dusts in Europe. A development can be foreseen of the processes now available for reprocessing of dust and also new processes for metal recovery are likely to develop. Presently, the building of a new reprocessing facility for zinc containing dusts in Sweden is being investigated.

Future changes may also occur within the manufacturing of metals by the steelworks e.g. increased requirements on the air cleaning system. The knowledge how dust can be recycled within the steelworks without disturbing the processes and the quality of the final products may also be increased.

Legislation

Special laws control the transportation and handling of hazardous waste. The dust from steelmaking industries can be defined as hazardous waste. However, it is not clear if a rest product representing a value should be defined as hazardous waste.

Export

The possibilities to export hazardous waste are now restricted. In the Basel convention, valid from 5 Maj 1992, the import and export between countries of hazardous waste for final treatment is controlled. The convention is presently ratified by 20 countries.

In accordance with the Basel convention an export permit for the waste can only be given if one of the following conditions are fulfilled:

- limited processing capacity or facilities for final treatment of the waste in the exporting country
- the waste is required as raw material at the recovery facility in the importing country
- the transport is in agreement with other criteria between the parties and in agreement with the goals of the convention

Export to other countries is not allowed except if other bilateral, multilateral or regional contracts are signed and that these contracts are in agreement with the goals of the Basel convention. A regional contract for transportation and recovery of hazardous waste has been signed by the OECD countries. The OECD agreement coincide to a large extent with the roles in the Basel convention.

It cannot be excluded that the possibilities to export and import hazardous waste to other countries will undergo more changes in the future.

Environmental laws

The requirements on Swedish and Norwegian steelworks on the release of dust to the environment are today the highest in the world. The release limits are related to the steel production and is equal to 0.1 kg dust per tonne steel, including also diffuse releases of dust. The limit values in other countries are based on the chimney release and are a factor of 10 higher, but will in 1995 be decreased by a factor of 5.

The motivation for reprocessing of dust is also environmental. If dust is to be disposed of, appropriate care must be taken with respect to conditioning of the waste and repository design so that toxic metals in the dust are not leached to the environment. In dust especially Cr and Zn are easily the leached. The Swedish environmental authorities advocates a reprocessing of dust both for environment protection and for saving valuable mineral resources.

In late 1992 will the Swedish Environmental Protection Agency present a proposal for the handling of the various waste types from the iron steel industry. The proposal will contain recommendations on the alternatives reprocessing and advanced disposal for the various dusts.

Others

Another factor that may influence the possibility of melting exempted steel waste and the reprocessing of dust from such melting is the reluctancy of the producers to take in radioactive materials in their processes. This may be due to fear of negative reactions from workers or consumers.

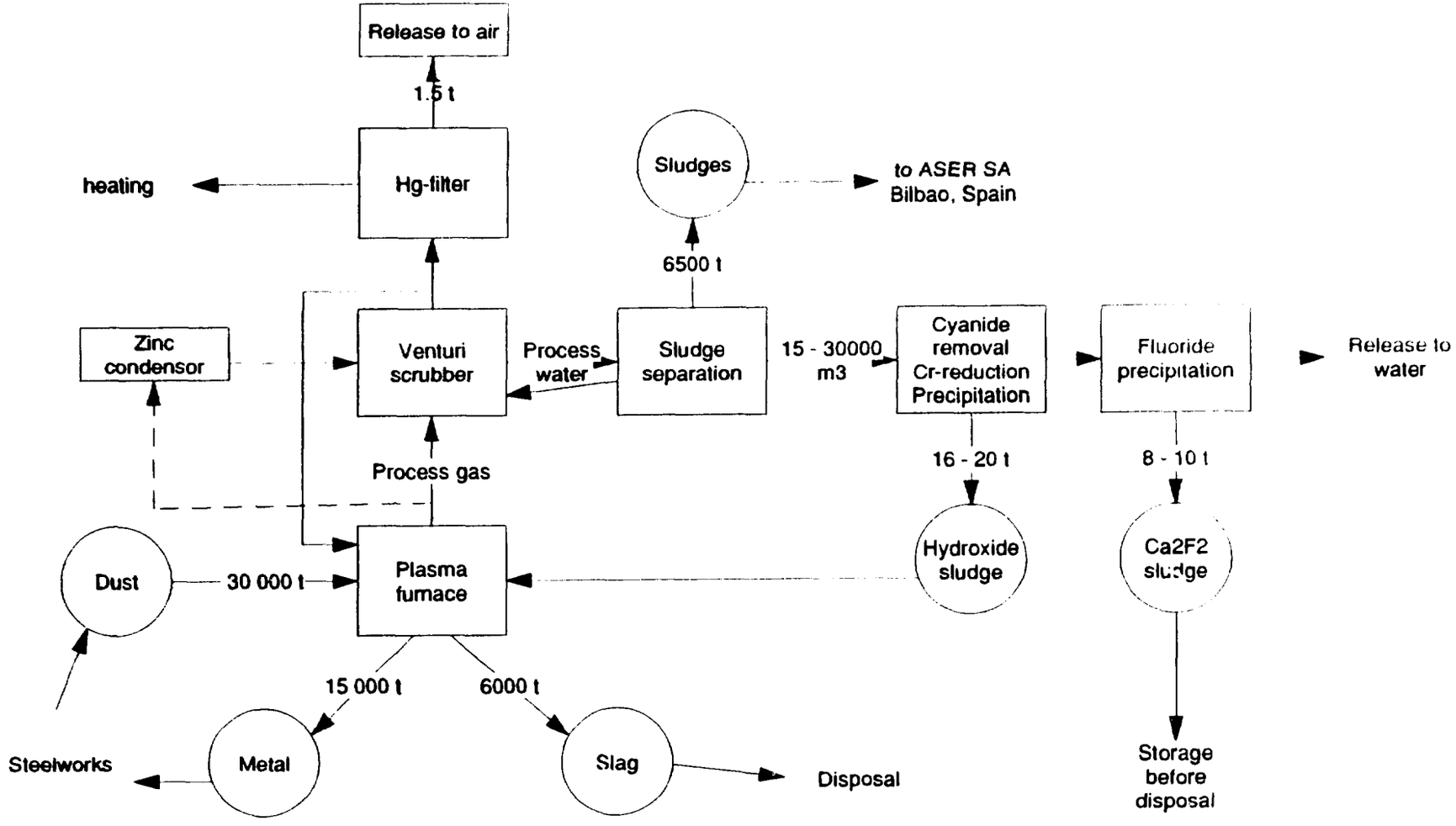


Figure 3.1 Flow scheme of the plasma furnace process at ScanDust, Sweden

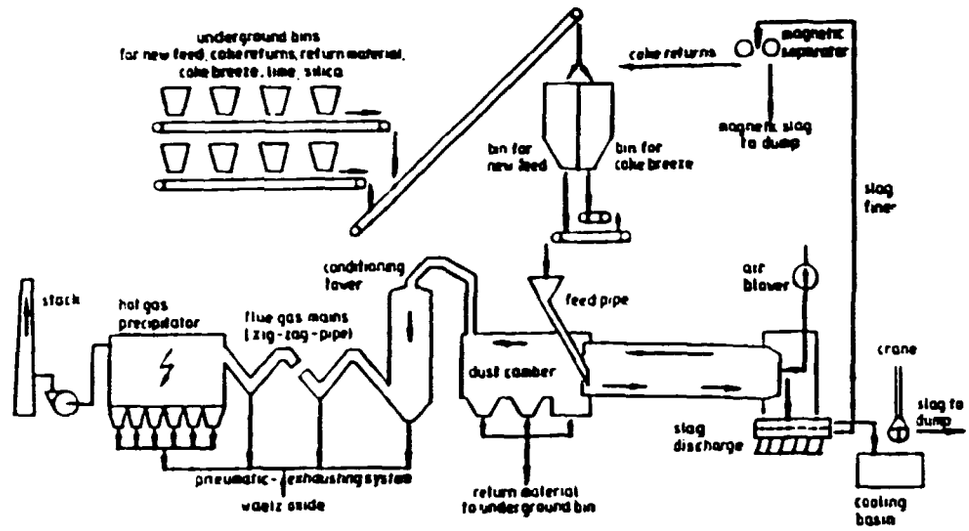


Figure 3.2 Flow Scheme of the Waelz process at Berzelius, Duisburg [*Maczek and Kola, 1980*]

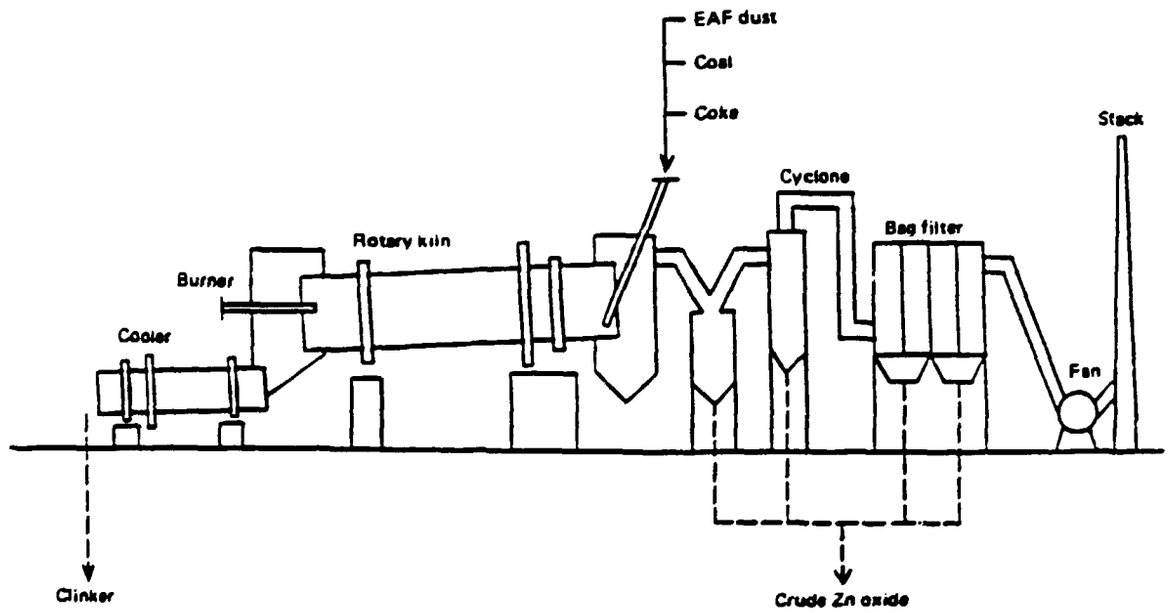


Figure 3.3 Flow Scheme of the "HTR" process in Japan [*Mac Rae, 1985*]

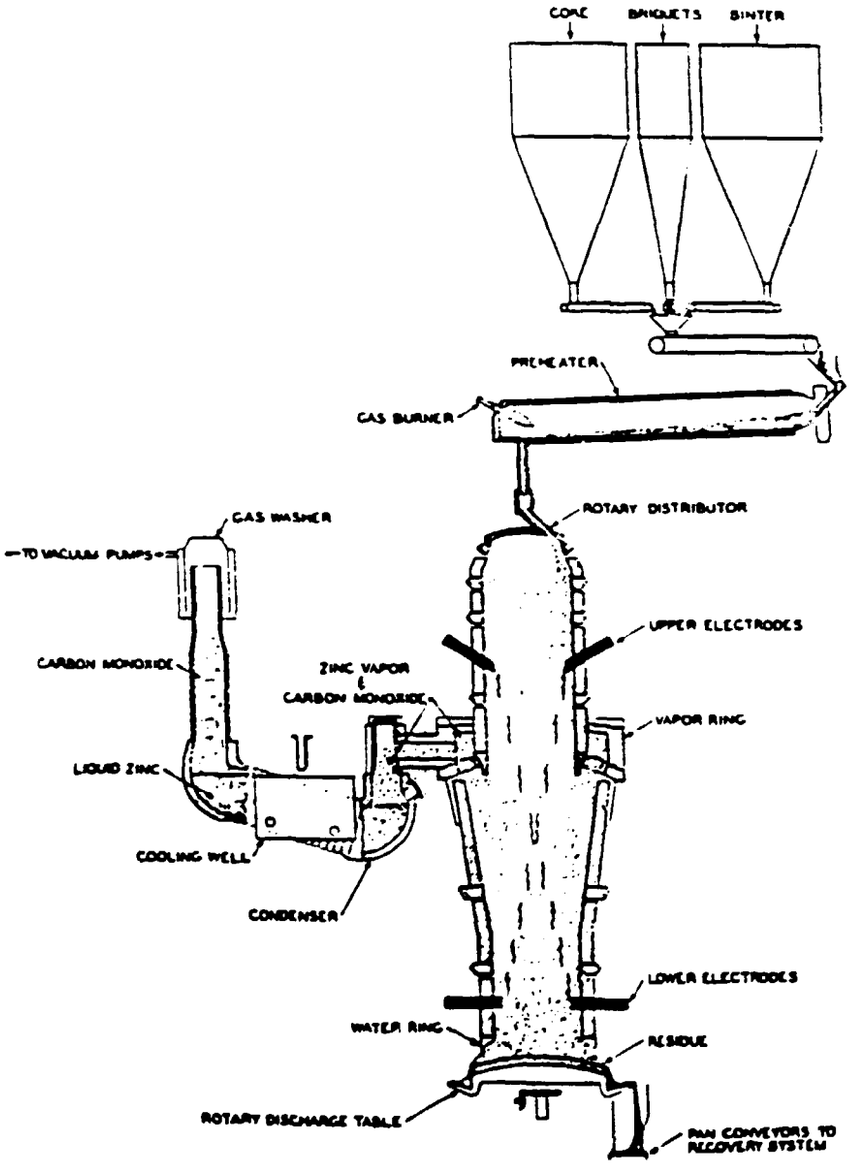


Figure 3.4 Flow Scheme of the St. Joe smelter process in USA [*Mac Rae, 1985*]

Table 3.1 Analyses of iron based alloy, slag and sludges from reprocessing of dust at ScanDust [*Johansson and Löfgren, 1990; Ulf Helgesson, ScanDust, Pers. comm.*].

	Elemental composition (%weight)				
	Dust	Metal	Slag	Venturi sludges	Waste water
Fe	23.0%	60.0%	3.0%	5.5%	
Cr	7.4%	20.0%	5.0%		0.1 mg/l
Ni	1.7%	5.0%	0.2%	0.9%	0.02 mg/l
Mo	0.4%	1.0%		0.6%	
Cu	0.2%	0.3%		1.0%	0.12 mg/l
Mn	3.0%	3.0%		6.7%	
CaO	8.0%		29.0%	4.0%	
SiO2	9.0%		30.0%		
Al3O2	2.0%		7.0%	1.8%	
MgO	3.0%		10.0%	3.7%	
V2O5	0.2%	1.0%			
Ba	0.02%				
Zn	4.0%		0.01%	18.4%	0.08 mg/l
Pb	0.8%		0.0005%	6.0%	0.01 mg/l
Cd	0.03%		0.0002%	0.1%	0.003 mg/l
Hg	0.0005%		0.00001%		0.0005 mg/l
Cl	0.7%		0.01%		0.7%
F	0.5%		0.6%		20 mg/l
K	1.0%			3.0%	0.6%
Na				4.5%	0.7%
Co				0.04%	

Table 3.2 Analyses of incoming electric furnace dust, Waelz oxide and slag referring to normal operation at Berzelius, Duisburg (in weight percent) [*Maczek and Kola, 1980*].

	E F Dust	Waelz oxide	Slag
Zn	22-24	54-56	0.3-0.6
Pb	4-5	9-11	0.2-0.4
Cd	0.03-0.1	0.1-0.2	-
Cu	0.2-0.4	0.03-0.04	0.3-0.5
Sn	0.2-0.3	0.2-0.4	0.1-0.2
As	0.04-0.08	0.01-0-02	0.05-0.1
S_{total}	1.8-2.2	1.4-1.8	1.5-2.5
F	0.2-0.4	0.4-0.8	0.1-0.2
Cl	1-1.5	2-4	0.03-0.05
C	1-2	0.2-0.8	5-10
FeO	26-30	3-4	34-38
MnO	4-5	0.6-0.8	5-6
CaO	6-7	0.6-0.8	5-9
MgO	2.5-3.0	0.4-0.5	3-4
BaO	~0.01	~0.01	~0.1
Al_2O_3	0.4-0.6	0.1-0.15	2.5-3.5
SiO_2	3-3.5	0.5-0.7	35-37
Na_2O	1.5-1.9	2-2.5	1.2-1.6
K_2O	1.2-1.5	2-2.5	0.7-0.9
moisture	9-11	0.1-0.2	-

Table 3.3 Estimated distribution of radionuclides during reprocessing at ScanDust.

	Percent of activity in incoming dust				
Element	Steel	Slag	Venturi sludges	OH-sludges	CaF2 sludges
Mn	50.0%	10.0%	50.0%	1.0%	1.0%
Fe	100.0%	2.0%	5.0%	1.0%	1.0%
Co	100.0%	1.0%	20.0%	1.0%	1.0%
Ni	100.0%	2.0%	10.0%	1.0%	1.0%
Zr	1.0%	1.0%	100.0%	1.0%	1.0%
Sr	1.0%	70.0%	10.0%	1.0%	1.0%
Zr	100.0%	1.0%	0.5%	1.0%	1.0%
Nb	100.0%	10.0%	1.0%	1.0%	1.0%
Tc	100.0%	100.0%	100.0%	1.0%	1.0%
Ru	10.0%	100.0%	100.0%	1.0%	1.0%
Sb	100.0%	1.0%	100.0%	1.0%	1.0%
Cs	1.0%	1.0%	50.0%	1.0%	1.0%
Eu	100.0%	100.0%	1.0%	1.0%	1.0%
Np, Pu, Am, Cm	10.0%	100.0%	1.0%	1.0%	1.0%

4 RADIOLOGICAL CONSEQUENCES

Estimates have been made of the possible radiological consequences of reprocessing dust arising from melting of steel scrap from decommissioned nuclear power plants. In this chapter a presentation is made of the scenarios evaluated, the calculation methodology used, and the resulting doses.

4.1 Definition of scenarios

The reprocessing of dusts from steel melting gives rise to a number of products and residues. The residues may be further processed, reused as filling material or disposed. The activity concentration in these materials may for certain radionuclides be different than of the exempted waste. Of importance are those materials in which a reconcentration of radiologically important radionuclides may occur. Based on the analysis presented in Chapter 3 two scenarios for the consequence calculations have been chosen. These are:

-Reprocessing of stainless steel dust at ScanDust
-Exposure from products made by reprocessed zinc

The exposure pathways that have been considered are external exposure and when applicable inhalation of dust with radionuclides.

The melting of the exempted steel from one nuclear power reactor has been estimated to give rise to 50 tonnes of dust. The decommissioning of all twelve nuclear reactors in Sweden would give rise to approximately 600 tonnes of dust. During the processing steps, the scrap melting and the dust reprocessing, a mixing with material of other origin may occur. Since it is difficult to determine the degree of mixing it has been assumed in the calculations that the melting of the exempted decommissioning scrap will be performed in campaigns. Thus no mixing with materials of other origin is assumed to occur. Each campaign has been assumed to comprise 50 tonnes of dust arising from the melting of 5000 tonnes of exempted steel scrap from one nuclear reactor. Thus, a relatively small amount of dust with a maximum activity concentration will be reprocessed in a short time interval. If reprocessing in campaigns is not used, the scrap or dust will be mixed with material of other origin. The result will be a lower activity concentration in the various materials, but also a longer processing time and thereby a longer exposure time. The resulting doses are thus not likely to differ substantially from those estimated assuming a campaign handling.

Many of the radionuclides present in decommissioning waste have a short radioactive half-life. The activity concentration in the dust will therefore depend on the time span between the exemption and the reprocessing of the dust. In the calculations a period of one year has been assumed between the exemption and the dust reprocessing.

4.2 Methods to estimate dose

The effective dose from inhalation and external dose is calculated for a maximally exposed individual. The effective dose is here the sum of the weighted values of the mean committed dose equivalent in the different organs or tissues receiving dose. The weighting is based on the proportion of the stochastic risk resulting from the organ or tissue considered to the total risk, when the body is irradiated uniformly. A committed dose is the dose integrand over the 50 years after intake of radioactive material into the body. Committed dose equivalents per unit of intake from NRPB have been used in the calculation of dose from inhalation and ingestion [*NRPB, 1987*].

The external dose is here the dose equivalent from external uniform irradiation of the whole body.

The calculation models developed in the previous study has been used to estimate the radiological doses [*Elert et al., 1992*]. The mathematical expression used will be briefly described below. The selection of input data for the different scenarios will be described in Section 4.3.

Activity concentration

The activity concentration in the waste will vary with time due to radioactive decay. The initial activity concentration is taken as the concentration at the time of exemption, that is one year after the shutdown of the reactor. The activity concentration at time t is given by:

$$A_i(t) = A_0 \cdot e^{-\lambda t}$$

where:

A_0	is the initial activity concentration [Bq/g]
λ	is the decay constant of the radionuclide ($\lambda=\ln 2/T_{1/2}$) [a^{-1}]
$T_{1/2}$	is the radioactive half-life of the radionuclide [a]
t	is the time after exemption [a]

Dose from inhalation

The individual dose due to inhalation of dust is calculated as:

$$D_{inh,i} = t_{exp} \cdot C_{air} \cdot BR \cdot DF_{inh,i} \cdot A_i(t) \cdot F_{Al}$$

where:

$D_{inh,i}$	is the inhalation dose for radionuclide i, [Sv/a]
t_{exp}	is the exposure time [h]
C_{air}	is the average dust concentration in the air [g/m^3]
BR	is the breathing rate [m^3/h]
$DF_{inh,i}$	is the inhalation dose factor for radionuclide i [Sv/Bq]

$A_i(t)$ is the activity concentration in the waste of radionuclide i [Bq/g] at the time t

F_{Ai} is the activity concentration in the dust divided by the activity concentration in the exempted waste [-]

Dose from external irradiation

The individual dose from external irradiation is given by:

$$D_{ext,i} = t_{exp} \cdot E_{\gamma,i} \cdot A_i(t) \cdot EF \cdot F_{Ai}$$

where:

$D_{ext,i}$ is the dose from external exposure of radionuclide i [Sv/a]
t_{exp} is the exposure time [h]
$E_{\gamma,i}$ is the average photon energy per disintegration [MeV]
A_i is the activity concentration of radionuclide i in the waste [Bq/g]
EF is an exposure factor taking into consideration geometry and self-shielding [(Sv/h)/(MeV·Bq/g)]
F_{Ai} is the activity concentration in the material giving external exposure divided by the activity concentration in the exempted waste [-]

The exposure factor will depend on the actual energy of the emitted photons. Many radionuclides emits several photons with different energy. Thus, in a detailed analysis the energy spectrum should be taken into consideration. However, in this study an average energy value has been used and the exposure factors have been based on an energy of 1 MeV. This will overestimate the external dose for radionuclides emitting low energy photons, but will be fairly accurate for the radionuclides of most importance for the external dose (e.g. ^{60}Co, ^{137}Cs, ^{54}Mn). The error introduced by this simplification is deemed to be small compared to the errors introduced by other uncertainties, e.g. in geometry and shielding factors. The average photon energy per disintegration are taken from ICRP 38 [*ICRP, 1983*].

4.3 Estimated radiological doses

4.3.1 Reprocessing of stainless steel dusts at ScanDust

Dust originating from steelworks producing stainless steel is likely to be reprocessed at the ScanDust facility in Landskrona in southern Sweden. The 50 tonnes of dust arising from melting the steel from one nuclear reactor corresponds to roughly 0.1% of the annual reprocessing capacity at ScanDust. It has therefore been assumed that the dust can be reprocessed in one working day, and an exposu :time of 8 hours has been used for the external dose and inhalation dose calculations. It should be noted that the exposure time for the various materials at the facility may be different, due to differences in storage times and handling procedures. However, the estimated doses can be used as references values for extrapolations for other exposure times.

The materials considered are the incoming dust, the reprocessed metal, the slag and the sludges from the venturi scrubber. The other residues from ScanDust for which a reconcentration of radionuclides may occur are the hydroxide sludges and the calcium fluoride sludges. However, the radionuclide distribution in these is very uncertain.

In the calculations, the three inventories presented in Table 2.1 have been used, assuming a total activity concentration of 1 Bq/g in the exempted steel waste. The external dose has been calculated assuming cylindrical sources with self shielding. The assumed radii, lengths, exposure distances, and the used exposure factors are given in Table 4.1. The dimensions of the sources correspond to the volumes that would arise from a campaign with 50 tonnes of dust. The exposure time is 8 hours.

Several of the materials at ScanDust are not likely to give rise to large amounts of airborne dust. The slag has a rather glassy character [*Johansson and Löfgren, 1990*], and the sludges from the wet gas cleaning system will have a high water content [*ScanDust, 1990*]. Also the incoming dust has been watered in order to avoid excessive dusting. In this study no attempt has been made to evaluate dust concentrations in different parts of the plant. However, an evaluation of the effect of a possible dust formation has been made assuming a dust concentration of 1 mg/m^3. As a comparison the threshold value for metallic nickel is 0.5 mg/m^3 and for respirable iron oxide 3.5 mg/m^3 [*AFS, 1990*]. The inhalation doses are based on an exposure time of 8 hours.

The doses arising from reuse of the slag from the reprocessing as filling material will be lower than the doses from reuse of slag from the steelworks since the activity concentration in the ScanDust slag is estimated to be lower than in the steelwork slag.

The venturi sludges will be sent for further reprocessing of zinc. However, the amounts arising from a campaign with dust from melting of exempted waste will be very small. The 50 tonnes of dust will give rise to roughly 10 tonnes of venturi sludges. The radiological consequences of the further reprocessing of zinc is evaluated in Section 4.3.2 and has therefore not been analyzed separately.

The estimated external doses are presented in Table 4.2 and in Figure 4.1. As a reference also the dose from pretreatment of the exempted steel scrap is included. For all inventories will the major contribution come from the external exposure during the handling of the incoming dust. The second highest contribution comes from handling of the venturi sludges. Assuming a radionuclide composition as for Inventory 1 (see Table 2.1), the dose from the dust handling will be roughly five times higher than that obtained from the pretreatment of the steel scrap [*Elert et al., 1992*]. The major contributing radionuclides are ^{137}Cs, ^{134}Cs and ^{125}Sb,. For Inventory 2, the total dose from handling of the dust is estimated to be lower than the dose obtained from the pretreatment of the steel scrap. The major radionuclides are ^{60}Co, ^{137}Cs and ^{54}Mn. With Inventory 3, the external dose from dust handling will be roughly twice that from the scrap pretreatment, with ^{137}Cs as dominating radionuclide. The relatively high doses from the dust treatment are due to the high exposure factor in combination with the enrichment of cesium in the dust.

Table 4.3 and Figure 4.2 present the estimated inhalation doses. These doses should not be seen as predicted doses, but more as an indication of the potential danger of dust formation. The inhalation doses obtained during the pretreatment of the steel scarp before melting is given as a reference. The materials with a major potential for giving rise to

inhalation doses are the hydroxide sludges and the fluoride sludges. These materials have a very high water content and are thus not likely to give off airborne dust. The hydroxide sludges are recycled within the reprocessing plant, while the fluoride sludges are disposed of as waste and may give rise to dust formation if not handled properly. The estimated doses from the fluoride sludges are lower than the inhalation doses estimated for the pretreatment of the scrap before melting for all inventories. The radionuclide concentration in the fluoride must be regarded as very uncertain. Of special interest is the concentration of ^{90}Sr which is the dominating radionuclide for all inventories. Inventory 1 also has a high content of actinides which also give a significant contribution to the dose.

4.3.2 Exposure from products made by reprocessed zinc

An estimate has been made of the radiological consequences from products made by reprocessed zinc. As a "worst case" a hypothetical scenario has been used where it is assumed that the radioactive ^{65}Zn from the exempted waste is mixed with the non-active zinc from the scrap metal during the melting in the arc furnace. After that no dilution with zinc from other sources is assumed to occur. This is a highly unlikely scenario, since it assumes that roughly one tonne of zinc metal can be produced without any dilution with zinc from other sources except in the melting.

The activity concentration in the zinc has been estimated to be 15 Bq/g based on an activity concentration of 0.3 Bq per gram of arc furnace dust and a non-active zinc content of 2%, corresponding to a dust with a low zinc content. The external exposure from a small item made by the zinc has been estimated to be $2 \cdot 10^{-5}$ Sv/a assuming an exposure time of 1800 hours per year. In this calculation has the radioactive decay of ^{65}Zn been neglected. The radioactive half-life of ^{65}Zn is 0.67 years. Thus the activity will soon reach negligible levels. After 5 years only 0.6% of the initial activity will remain.

Table 4.1 Data used in external exposure calculations.

Material	Weight (tonnes)	Number	Radius (m)	Length (m)	Density (kg/m3)	Distance (m)	Exposure factor (Sv/h)/(MeV Bq/g)
Dust	50	8	1	1	2000	2	8.18E-08
Metal	25	3	0.6	1	7860	2	1.18E-08
Slag	10	1	1	0.4	7860	2	1.02E-08
V-sludge	10	1	1.5	1	1500	2	2.05E-08
OH-sludge	0.05	1	0.5	0.05	1200	2	8.40E-10
F-sludge	0.05	1	0.5	0.05	1200	2	8.40E-10

Table 4.2 Estimated external doses from reprocessing of steelwork dust arising from melting 5000 tonnes of exempted steel waste (Sv).

	External dose (Sv) per 5000 tonnes of steel		
	Inv 1	Inv 2	Inv 3
Pretreatment	2.01E-06	9.79E-07	8.90E-07
Dust	6.27E-06	6.09E-07	4.20E-06
Metal	5.69E-07	7.99E-08	7.74E-08
Slag	3.91E-08	7.51E-09	3.04E-08
V sludge	4.29E-06	2.50E-07	2.34E-06
OH-sludge	9.66E-07	9.39E-08	6.47E-07
F-sludge	1.93E-06	1.88E-07	1.29E-06

Table 4.3 Estimated inhalation doses from reprocessing of steelwork dust arising from melting 5000 tonnes of exempted steel waste (Sv).

	Inhalation dose per 5000 tonnes of steel (Sv)		
	Inv 1	Inv 2	Inv 3
Pretreatment	1.24E-06	1.04E-07	2.50E-07
Dust	4.28E-09	3.47E-10	3.80E-09
Metal	1.12E-09	1.87E-10	2.28E-10
Slag	1.27E-08	5.98E-10	9.54E-09
V-sludge	4.04E-09	3.34E-10	3.66E-09
OH-sludge	6.43E-08	5.21E-09	5.71E-08
F-sludge	1.29E-07	1.04E-08	1.14E-07

Figure 4.1 Estimated external doses from reprocessing of steelwork dust arising from melting 5000 tonnes of exempted steel waste (Sv).

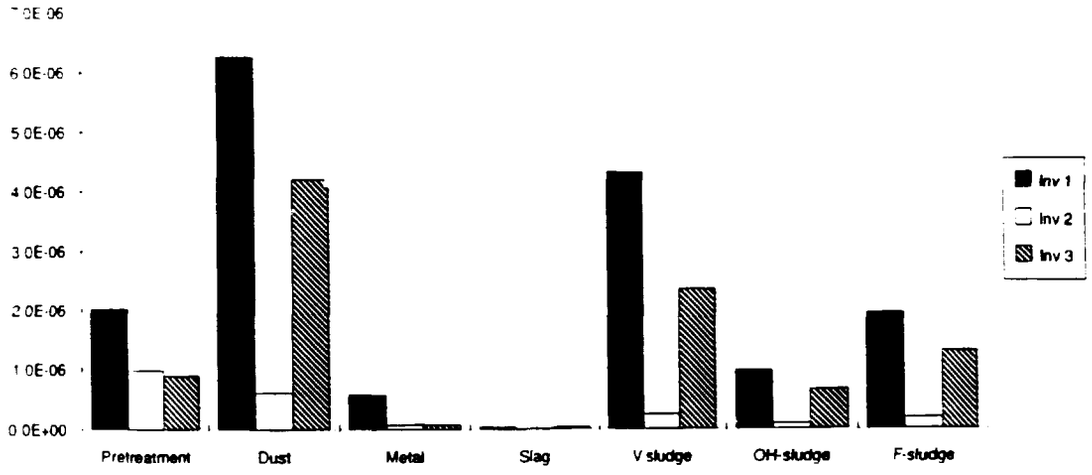
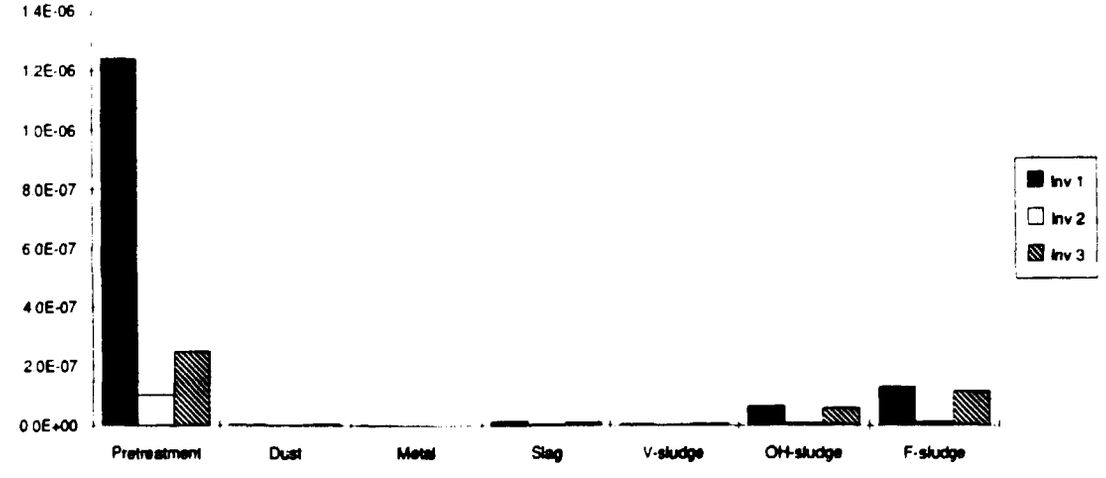


Figure 4.2 Estimated inhalation doses from reprocessing of steelwork dust arising from melting 5000 tonnes of exempted steel waste (Sv).



5 CONCLUDING REMARKS

Reprocessing of dust from electrical arc furnaces is becoming more and more common. The main reason for reprocessing is environmental concern. The dusts contain easily leached heavy metals that are toxic to the environment. Another aspect considered is resource saving, since the dust contains metals that can be recovered. However, the present metal prices are at a very low level so there is for the moment no strong economic motives for reprocessing.

Today large amounts of dust are stored awaiting reprocessing. Dusts from steelworks making stainless steel is sent or will be sent to ScanDust for reprocessing. The options for dust with a high zinc content are presently unclear. Previously this dust has been sent to Germany or Spain for reprocessing, but since there presently is a low capacity for dust recovery in Europe they are temporarily stored awaiting future reprocessing. Presently the possibilities of building a new facility in Sweden is being investigated. Several different methods are being evaluated.

The potential for reconcentration of radionuclides during the dust reprocessing has been evaluated with the main focus on the only process presently in use in Sweden, the plasma process at ScanDust. During the process the dust is heated to high temperature and a further separation of volatile radionuclides will occur. Very small amounts of dusts would arise from melting of exempted steel scrap compared to the total amounts reprocessed at the facility. There may thus be a considerable mixing with dusts of other origin. However, if dusts arising from melting of large amounts of exempted steel scrap is reprocessed in a campaign, temporarily increased radionuclide concentrations may arise in some of the residues from the process gas cleaning system. The system presently used in ScanDust is a wet system where several different residues are obtained. Some of these are further processed and some are disposed of as waste. Residues occurring in small amounts may potentially be enriched with some radionuclides. A dry gas cleaning system would probably have a smaller potential for reconcentration of radionuclides than the presently used wet system, since the number of cleaning steps and the number of residues would be reduced.

The degree of enrichment is difficult to predict with great certainty. The decommissioning waste will also contain radionuclides with a very large variety of physical and chemical properties. However, the radionuclides normally of most significance are either ferric metals (^{54}Mn or ^{60}Co) and are unlikely to be enriched in any larger degree, or alkali and alkaline earth element (^{137}Cs and ^{90}Sr, respectively). The dusts will contain relatively large amounts of potassium and calcium and the cesium and strontium are likely to end up in the same residues as these elements. This will put a upper limit on the possible enrichment of the cesium and the strontium.

The estimated external doses from dust reprocessing are somewhat higher than the doses obtained during the steel melting and the pretreatment of the exempted steel scrap. This is mainly due to the enrichment of cesium. However, the doses from dust reprocessing are lower than the doses that may be obtained from the use of products made by exempted steel. The inhalation doses from reprocessing of dust at ScanDust are estimated to be low. They major reason is that the residues are in such a form that they will not easily be

aerosolized. Furthermore, the major contributor to inhalation dose, ^{90}Sr, is only partly enriched in the dust.

Some residues are further processed for recovery of zinc and lead. It is unlikely that this processing will give rise to a further reconcentration primarily due to the large degree of mixing with materials from other sources. The processes used for the zinc and lead recovery gives rise to residues mostly in the form of slags which may be reused. However, the potential for a reconcentration of radionuclides in the slags is low. The doses due to reconcentration of radioactive zinc as a the result of the zinc recovery has been estimated to be very low, even neglecting the dilution that will occur in the recovery process. The short radioactive half-life of zinc will also reduce the consequences.

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