



CLASSIFICATION OF SOLID RECOVERED FUELS

Authors:

Joop van Tubergen, Essent Milieu, j.van.tubergen@essent.nl
Dr Thomas Glorius, RWE Umwelt, thomas.glorius@rwe.com
Eric Waeyenbergh, Scoribel, eric.waeyenbergh@holcim.com

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PREFACE

This document has been drafted on request of CEN/TC 343 Working Group 2 “Fuel Specifications and Classes”. The WG wanted to establish a classification system using practical data on Solid Recovered Fuel (SRF) composition and use. Therefore some delegates involved in the production and use of SRF offered to draft this document.

The WG decided on a classification system based on a limited number of properties. Originally the WG asked for a document covering 7 key properties of SRF: NCV, moisture, ash, Cl, Hg, Cd+Tl and sum of heavy metals. The first draft of the document was discussed at the WG meeting in Lyon on 15 and 16 September 2003. The properties of SRF and the experience with the different technologies were accounted for in the proposed classification system. The emission limit values of the Waste Incineration Directive played a decisive role in establishing the maximum possible content of heavy metals in SRF used as substitute fuel in different technologies.

The WG decided at the meeting in Lyon to reduce the number of key properties from 7 to 3: NCV, Cl and Hg content.

Topics were added covering the questions that had been raised at the Lyon meeting:

- justification of units chosen (annex 3)
- justification of the use of 50th/80th percentile values (annex 5)
- evaluation of data and influence on boundaries of classes (annex 5)
- justification of the boundaries of classes (annex 8)

The main adjustments were made in section 5. The annex 5 and tables 18 and 20 of section 5 have been written with support of Ms Sabine Flamme of INFA.

Concerning the questions raised at the Brussels meeting on 9 and 10 February 2004 and the meeting in Obourg on 24 September 2004 modifications have been made:

- The classification of Cd and Tl has been evaluated using practical data. A classification system for Cd has been added if it comes to a need for that.
- Additional evaluation of proposed classes of Cl and NCV with practical data has been included.

In making acknowledgements, we should like to express appreciation to the members of CEN/TC 343 WG 2, the members of ERFO and particularly to those companies for making available data and information from their experience with the production and use of Solid Recovered Fuel.

1. INTRODUCTION

Energy intensive industries are looking for alternative fuels in order to save primary fuels, and by doing so, enforce the development of sustainable development.

The waste management sector industry has developed, since many years, ways to produce secondary fuels e.g. SRF's with reliable qualities, which are used successfully regarding economic and environmental aspects.

However, this way of recovery is not optimized because of some practical uncertainties like:

- obtaining permits to use SRF as an energy source,
- transborder shipment regulation and problems in creating a European market for SRF
- unclear classification of the SRF in the EC waste list
- doubts about reliable qualities of some SRF
- doubts about effect on the processes and installations.

Therefore CEN has received the mandate to establish a set of standards for solid recovered fuel (SRF) prepared from non hazardous waste. CEN/ TC 343 decided to separate the task in five different working groups (WG1-5).

WG 2 has received the task to prepare a proposition of classification system, classes and specifications.

The following document gives a technical approach based on the processes of final users that have been identified as being (potentially) interested and qualified for the use of SRF on the one hand, and the practical and actual experience of SRF produced in Europe on the other hand.

SRF may only be used by installations complying with the emission limit values set by the Waste Incineration Directive (WID). This document is based on the characteristics that the SRF should present, in order to fulfill the criteria of the WID and the technical request of the installations. That does not alter the fact that other properties are also of interest considering the specific requirements for different users.

The classification system, the classes and the specifications that are proposed in this document should help the authorities in writing the permits, be a help for the final user to understand easily what has to be taken into account when dealing with SRF and should increase the positive perception of the public on the use of SRF by saving of natural resources. For example about 50% of the primary fuel consumption of cement kilns and a substantial share of hard coal and lignite for power production could be substituted by waste. The potential for European Solid Recovered Fuels in 2005 is estimated at more than 10 Mt/a /1/, which corresponds to a CO₂-reduction of more than 10 Million tpa. (In this figure only the biogenic fraction and C/H ratio were considered. The reduction due to less emission of methane from landfills would be a factor ~3 of this).

It is of importance to mention that the standardization concerns big SRF streams. It surely does not exclude the possibility to use alternative fuels with other limits or specifications than those presented in this document. In that case, the waste fuel will not be standardized.

Selection of properties for classes and specifications:

A classification system is a system of classes with limit values and valid for all kind of users. Specifications concern specific information related to potential risks for different technologies and plants.

Implementing such a system should facilitate trans-boundary shipments, permitting and control for the user of standardized recovered fuels (SRF).

CEN/TC 343 WG 2 has agreed that key properties mentioned below will be used to establish the classification and the specification system for SRF. These properties are significant for one or more of the following aspects: economics (NCV), technology (CI) and emission (Hg+Cd). CI has to be mentioned, because of the great importance in corrosion, slagging and fouling of boilers. It has been suggested to consider both Cd and Tl. However, the concentration of Tl in SRF is practically nil (see also annex 9), applying this element as part of an environmental parameter would be meaningless.

Table 1 Key combinations of properties and aspects

<i>Properties</i>	<i>Key aspect</i>
NCV	Economics
Cl *	Technology
Hg +Cd	Emission

* Cl may influence emissions of HCl and some heavy metals as chlorides. However, the effect is estimated to be negligible. An influence on formation of PCDD and PCDF is unlikely under the process conditions in a coal fired power plant and a cement kiln.

2. OVERVIEW OF PRACTICAL DATA

2.1 Specification of users

At present the main end-user is the cement industry. But also in lime kilns SRF is used successfully since many years. As the technology of cement kilns and lime kilns is very similar in this report cement kiln also stands for lime kiln except for heavy metals. However, the market opportunities in the potential bigger market of the power generation sector are increasing. The fourth sector that may become a substantial outlet for SRF is cogeneration CHP (district heating) /1/. Main technologies involved are cement kilns, pulverized coal fired power plants and FBC (fluidized bed combustion) plants. See also annex 1.

2.1.1 Cement industry

The cement industry has a broad experience in the use of waste derived fuels. Hazardous and non hazardous wastes are processed and used as secondary fuel or a mixture of secondary fuel and raw material. Originally the substitution of primary fuels was practised by wet processes, which have higher specific energy consumption than the dominant dry process for the production of clinker. But the use of waste derived fuels, including SRF, is also increasing in the dry process. Cl may cause substantial problems in the dry process in blocking the pre-heater with condensed volatile chlorides. Using a so-called salt bypass increases the tolerance for Cl in the input. Table 2 shows the requirements for SRF. Figures are based on specifications from the end-users from e.g. Belgium, Germany and France.

Table 2 Specifications /2/

	<i>Unit</i>	<i>CK</i>
NCV	MJ/kg ar	5/10-12/22*(mean values)
Cl **	% ar	0.5-1.0 (mean)1-3.0(max)

CK =cement kiln or clinker kiln

* There is no maximum value for NCV. The combination of material and energy recovery together in clinker kiln allows the use of poor calorific values, because the ash content in the SRF does not contribute to the energy input.

** Cl specification depends on the composition of the input. At high substitution rates, the limits are in the range of 3% for a cement kiln with a by-pass (depending on the K, Na content) and for a kiln without this system 0.5-1.0%. For cement kilns with a wet process the maximum for Cl is 6%.

2.1.2 Coal fired power plants

The experience of the power generating plants with SRF is limited to a few plants in Germany and The Netherlands that are using SRF since 2000 but still on a small scale. RWE Umwelt and RWE Power are carrying out the demonstration project RECOFUEL within the 6th Framework programme of the EU to use quality assured SRF's in lignite fired boilers.

Pulverized coal plants are dominant in the power generating sector. The technologies differ for brown coal and hard coal, as these coals have widely divergent heating values and material properties. Hard coal fired power plants using a dry bottom boiler (DBB) have less flexibility to the shape and dimensions of SRF than the wet bottom boiler (WBB) molten slag systems with cyclones. Table 3 shows the requirements for SRF. The data are based on specifications from end-users in The Netherlands and Germany.

Table 3 Specifications /2/

	<i>Unit</i>	<i>Hard coal DBB</i>	<i>Hard coal WBB</i>	<i>Brown coal DBB</i>
NCV	MJ/kg ar	13.5(mean) 11-18(range)	17(mean) 13-22 (range)	13.5(mean) 11-18 (range)
Cl *	% dry	0.6(mean) 1.3(max)	1.1(mean) 2.5(max)	0.5(mean) 0.6 max)/1.0(max)**

DBB : dry bottom boiler pulverized coal, dry ash

WBB : wet bottom boiler pulverized coal, molten slag

* The Cl-concentration of the total fuel mix should be kept <0.2 –0.4% to prevent high temperature corrosion. The maximum allowable Cl % depends on the design and materials chosen. In The Netherlands the maximum is usually 0.2%. In the UK the maximum is higher (0.4%) as the plants are designed for coal with a high Cl content.

** The maximum values vary for different companies. Mean and max.-values are close for a specific end-user.

2.1.3 FBC

Fluidized bed combustion plants (FBC) are used i.e. for district heating in Scandinavia and cogeneration (CHP), using mainly biofuels. Table 4 shows the requirements for SRF. The data are based on specifications of the end-users in Sweden, Italy and Germany.

Table 4 Specifications /2/

	<i>Unit</i>	<i>FBC</i>
NCV	MJ/kg ar	13.5 (mean) 9-18(range)
Cl*	% ar	0.4(mean) 0.5(max)/ 0.8 (max)/1.4(max)

* The maximum allowable Cl-content depends on the design of the plant and composition of the input. The mean and max values are close for a specific end-user.

2.1.4 Overview

Table 5 Overview of specifications (end-users)

<i>Unit</i>		<i>Cement</i>	<i>Hard coal</i>		<i>Brown coal</i>		
			<i>DBB</i>	<i>WBB</i>	<i>DBB</i>	<i>FBC</i>	<i>FBC(AC)*</i>
NCV	MJ/kg ar mean/max	5/11/22(mean)	13.5/18	17/22	13.5/18	13.5/18	13.5/18
Cl	% ar mean/max	0.5-1.0/3	0.5/1.0	1.0/2.0	0.4/0.5-0.7	0.4/1.4	0.4/1.4

* AC active coal used as absorbent

2.2 Orientation values of mercury and cadmium

The emission of heavy metals is an important topic in the market development of SRF although concerning the WID the heavy metal emissions by co-combustion plants are not considered any longer separately for heavy metals originating from SRF at one hand and at the other hand primary fuels, because the mixing rule has been deleted for these properties. The values derived in annex 4 only have an orientation character. The fuel mix, the raw material and the specific transfer factor of the plant involved together determine the actual emissions. Specifications provided by potential producers and users are often influenced by local limit values. This would not be a sound basis for a European classification system. But using the practical data on the transfer factors (see annex 2 for background information) and the values of the WID for the several technologies the maximum concentration in the SRF may be calculated according to the formula mentioned in annex 3.

Table 6 Overview of calculated orientation values of Hg and Cd

<i>Unit</i>	<i>Cement</i>	<i>Hard coal power Plants</i>		<i>Brown coal power Plants</i>		<i>FBC</i>	<i>FBC(AC)*</i>
		<i>DBB</i>	<i>WBB</i>	<i>DBB</i>	<i>DBB</i>		
Hg mg/MJ ar max	0.08-0.33	0.065	0.034	0.085		0.028	0.26
Cd	6.90	1.21	0.25	0.42		0.63	85

* AC: active coal used as absorbent

The values for Hg and Cd have to be understood as maximum average (see also Annex 5 chapter 1.2) that can be used in a process operation that comply with the transfer factor taken in the example above for the use of waste as a fuel. It is of importance that each plant that wants to use secondary fuel makes first a study to determine what the transfer factors are for each metal. The result shows significant differences between the processes and technologies used. It means that some technologies are not able to use the same fuels as other due to different transfer factors.

3. OVERVIEW OF SECONDARY FUEL AND SRF QUALITIES

Tables 7-10 give an overview of the composition of secondary fuels. The data are based on analysis of fuels produced in several EU Member States. See also annex 6.

SRF's derived from MSW have generally a lower NCV than the SRF's derived from selected commercial waste, which have a range that corresponds to the NCV of a mixture of biomass and plastics. The maximum of Hg for SRF derived from MSW is higher. However, the maximum for Hg is not substantially higher than for SRF derived from commercial waste when Tunka is excluded. The SRF's produced for cement kilns show a great range for all properties, indicating the flexibility of the cement kilns.

Secondary fuels may also contribute to the substitution of raw materials. This is often the case with secondary fuels used by cement kilns. Therefore two SFR categories are presented, one low in ash and one high in ash. The NCV value is low for the SRF types with high ash content. This has a direct effect on the values for Hg using the unit mg/MJ as can be seen in table 7.

Table 7 Overview of SRF with low and high ash content

<i>Unit</i>	<i>SRF low in ash*</i>		<i>SRF high in ash*</i>	
	<i>Median range</i>	<i>80th Percentile range</i>	<i>Median range</i>	<i>80th Percentile range</i>
NCV MJ/kg ar	11.7 - 25.5	12.8 - 25.8	3.2 - 10	3.4 - 12.0
C1 % ar	0.04 - 1.7	0.07 - 2.0	0.07 - 0.77	0.14 - 0.82
Hg mg/MJ ar	0.004 - 0.042	0.005 - 0.137	< 0.05 - 0.406	0.064 - 0.781
Cd + Tl mg/MJ ar	0.008-0.121	0.008-0.264	0.26-<0.93	0.26-0.94

* boundary 20% d

See also annex 7 for the maximum values of heavy metals

Table 8 Overview of SRF derived from MSW

<i>Unit</i>	<i>Median range</i>	<i>80th Percentile range</i>
NCV MJ/kg ar	9.8-19.9	11.4-22.2
C1 % ar	0.23-0.79	0.43-0.88
Hg mg/MJ ar	0.006-0.069	0.009-0.079
Cd + Tl mg/MJ ar	0.050-0.311	0.084-0.380

Table 9 Overview of SRF derived from commercial waste

<i>Unit</i>	<i>Median range</i>	<i>80 thPercentile range</i>
NCV MJ/kg ar	13.0-31.0	14.0-31.6
C1 % ar	0.04-0.60	0.07-1.0
Hg mg/MJ ar	0.004-0.019	0.005-0.064
Cd + Tl mg/MJ ar	0.008-0.060	0.008-0.129

Table 10 Overview of SRF produced for cement kilns

	<i>Unit</i>	<i>Median range</i>	<i>80 thPercentile range</i>
NCV	MJ/kg ar	3.2-25.5	3.4-25.8
C1	% ar	0.07-1.7	0.14-2.0
Hg	mg/MJ ar	<0.02-0.406	<0.02-0.781
Cd + Tl	mg/MJ ar	<0.12-<0.93	<0.12-0.94

4. SUMMARY OF EXISTING QUALITY SYSTEMS FOR SRF (FOR CHOSEN PROPERTIES ONLY)

Table 11 Summary of existing national standards

	Unit	Finland			Germany		Italy		
		Class I	Class II	Class III	median	80 th perc.	Units	standard	High qual.
NCV							MJ/kg ar	>15	>19
Moisture							% ar	<25	<15
Ash							% d	<20	<15
Cl	% d	<0.15	<0.5	<1.5			% ar	<0.9	<0.7
Hg	mg/kg d	<0.1	<0.2	<0.5	0.6	1.2	mg/kg d	<7 ***	<1
Cd + Tl	mg/kg d	<1.0	<4.0	<5.0	5	11		-	<4
Sum HM	mg/kg d				351*/1049**	1080*/2460**	mg/kg d	<1040	<350

- Notes: **1.** Finland: Tl is not mentioned. NCV is not mentioned either. Use 20 MJ/kg d for the calculations and 15% moisture.
- 2.** Germany: *SRF produced from specific wastes, **SRF produced from MSW. Actually, there exists no 80th percentile value for Cu (SRF from production specific waste, class 1) and Pb+Cu (SRF from HCF of MSW, class 2). According to the latest information received, these values will probably be 500 (Cu) and 500 (Pb) 1000 (Cu) respectively.
The NCV values for heavy metals are up to 16 MJ/kg d. for class 2 derived fuels and 20 MJ/kg d. for class 1. Use 15 MJ/kg ar and 15% moisture for calculations for class 2 and 20 MJ/kg ar and 15% moisture for class 1.
- 3.** Italy: The HM Sb, Co and V are not mentioned. The NCV is a minimum value. Value for Cu concerns soluble components. Value for Pb concerns the volatile part. Use the minimum NCV (calculated for d) for the calculations. The value for the standard quality in the table for the concentration of Hg *** is the sum of Cd +Hg.
- 4.** Preceding the implementation of national standards producers of SRF have developed their own quality systems /1/.

Table 12 Summary of existing standards, adapted and presented in uniform units

	Unit	Finland			Germany*		Italy	
		Class I	Class II	Class III	Median	80 th perc.	standard	High qual.
NCV	MJ/kg						>15	>19
Moisture	ar						<25	<15
Ash	%						<15	<13
Cl	% ar	<0.13	<0.42	<1.3			<0.9	<0.7
Hg	mg/MJ ar	<0.005	<0.01	<0.025	<0.026/0.034	<0.051/0.068	<0.35**	<0.045
Cd + Tl	mg/MJ ar	<0.05	<0.2	<0.2	<0.17/0.23	<0.38/0.51	-	<0.180
Sum HM	mg/MJ ar				<14.9/59.4	<45.9/139.4	<52***	<15.6***

- * Different values for SRF derived from production specific waste (first figure) and SRF produced from MSW (second figure).
- ** Cd+Hg. There is no separate value for this quality in the Italian standard, see also note 3 table 11.
- *** The sum property does not include several HM, see also note 3 table 11.

5 CLASSES

5.1 Resolutions of WG 2

The WG defined classification as: “The grouping of SRF’s into classes defined by boundary values for chosen fuel characteristics, to be used for trading as well as for information of permitting authorities and other interested parties”. Initially the WG adopted in the 1st resolution 7 properties for the characterisation of SRF: NCV, ash, moisture, Cl, Hg, Cd+Tl, sum of heavy metals. These properties were used in earlier drafts of this classification report. However, in resolution 3 the number of key-properties was reduced from 7 to 3 (table 13). The main argument being the complexity of the classification with so many properties. The properties chosen represent the following aspects: economic value (NCV), technological restrictions (Cl) and environmental impact (Hg).

After lengthy discussion the WG adopted in its 3rd Resolution the following **structure** for the characteristics of SRF classes for each of the three selected fuel characteristics.

Table 13 SRF classes (resolution Lyon)

Classification Property	Designation	Unit	Classes				
			1	2	3	4	5
Net calorific value	NCV	MJ/kg ar	<10	<15	<20	<25	>25
Classification Property			1	2	3	4	5
Chlorine	Cl	% d	<0.3	<0.6	<0.9	< 3.0	>3.0
Classification Property			1	2	3	-	-
Mercury	Hg	mg/kg	<x	<y	<z	-	-

At the meeting in Brussels on 9 and 10 February 2004 the WG decided that closed classes shall be used without overlapping between the classes. Lower limits of Cl and NCV as well as upper limits of Cl are still to be discussed by the full WG2. A proposal of the WG for new classification values to draft TS on Specifications and Classes was presented to CEN/TC 343 at the meeting on 11 February 2004 (table 14).

Table 14 SRF classes (resolution Brussels)

Classification Property	Designation	Unit	Classes				
			1	2	3	4	5
Net calorific value (NCV)	qp,net	MJ/kg ar mean	25<x<=45	20<x<=25	15<x<=20	10<x<=15	3<x<=10
Classification Property			1	2	3	4	5
Chlorine	Cl	% ar median	y<=0.1	0.1<y<=0.5	0.5<y<=1.0	1.0<y<=1.5	1,5<y<=6.0
Classification Property			1	2	3	4	5
Mercury	Hg	mg/MJ ar median 80th perc.	<0,02 <0,04	<0,03 <0,06	<0,08 <0,16	<0,15 <0,30	<0,5 <1,0

DG Environment raised doubts concerning the exclusion of cadmium and thallium as a property in the classification system. The WG decided that the occurrence of these elements in SRF would be investigated and evaluated. A proposal for an environmental property which may also include Cd and Tl, besides Hg, was required to be elaborated in a new draft of the classification document.

5.2 Discussion

5.2.1 Units

For NCV and Cl the usual units are preferred for the classification. In annex 3 it has been concluded that the preferred unit for NCV is MJ/kg ar. The unit for Cl maybe in practice wt% ar or d. The unit wt% d has finally been chosen for practical reasons as data are usually available on dry basis.. However, for Hg the unit mg/MJ over the usual mg/kg d is chosen with respect to comparability and environmental aspects.

5.2.2 Use of mean, median and 80th percentile

The statistical distribution of the data for NCV, Cl and Hg differs.

For NCV the distribution is normal. In this case the use of the mean value is appropriate (see also annex 8).

For Cl the distribution is usually normal but may be also skewed (see also annex 8). In the calculations for the classification a normal distribution has been assumed. Therefore the unit for Cl in table 14 is % d mean instead of % median.

In most of the cases Hg has a right skewed distribution (see annex 5). This has consequences for the determination of average and maximum values. The median is preferred as measure of location because of its robustness and being independent from the type of distribution. For those cases where a maximum value is required the 80th percentile is preferred. The combination of median and 80th percentile is an appropriate tool for the evaluation of sets of 10 data used in the classification. Then high values are only possible as single outliers, which are not relevant in the calculation of the emission.

5.2.3 Overlap of classes

The WG prefers closed classes without overlapping ranges between the classes. In those cases with only a given maximum value of a class (Hg), classification in a single class will be possible. However, having a given minimum and a maximum of a class (as has been proposed for NCV and Cl), there are SRF's who's classification will vary (see annex 8). In line with the approach used with Hg sets of 10 data were used for the classification of NCV and Cl. The 95 percent confidence interval of the mean value of sets of 10 data was calculated. For the classification the minimum value (NCV) or the maximum value (Cl) of the confidence intervals (ranges) has been used.

5.2.4 Boundaries of classes for NCV

The boundaries were set based on the properties of the SRF's and the requirements of the users. For many purposes the NCV should be between 10-15 MJ/kg. There are also clusters at about 5 on the one hand and 22 MJ/kg on the other hand. A class width for NCV of 5 MJ/kg was decided by the WG. Class 5 has a minimum at 3 MJ/kg ar, which refers to calculations based on adiabatic flame temperature and experience in cement kilns using SRF with a high ash and high water content (see also annex 8). A maximum is set at 45 MJ/kg ar being the realistic maximum for SRF's. Taking into account the proposal of using the minimum values for the classification (5.2.3) the classes will be as shown in table 15.

5.2.5 Boundaries of classes for Cl

The values for Cl relate to the properties of the SRF's and the requirements of the users as well. For many purposes the Cl content should be below 0,5 or between 0,5 and 1,0 %. Boilers can accept up to 0,3% without restrictions. The WG decided in Brussels on a maximum at 6% ar. In practice the maximum value for SRF found so far is for AT3 3.65%d (mean +1,96xstdev). A maximum of (about) 3%d seems more appropriate to distinguish SRF from other waste derived fuels. The maximum of class 1 as mentioned in the Brussels resolution seems too low to be practicable for reliable classification with only a few SRF's

classified as such. A maximum of 0.2% would guaranty more stable classification. The same applies for the maximum of class 2 where a maximum value of 0.6% has been set. Taking into account maximum values for the classification (5.2.3) the proposed classes will be as shown in table 15.

Table 15 Proposed classes for NCV and Cl content* (resolution Obourg 24 September 2004)

Classification Property	Designation	Unit	Classes				
			1	2	3	4	5
Net calorific value (NCV)	qp,net	MJ/kg ar mean	x>=25	x>=20	x>=15	x>=10	x>=3
Classification Property			1	2	3	4	5
Chlorine	Cl	% d mean	y<=0,2	y<=0,6	y<=1,0	y<=1,5	y<=3,0

*based on sets of 10 data

An overview of the classification of the SRF's mentioned in Annex 8 is shown in table 16

Table 16 SRF classification* for NCV and Cl

SRF designation	NCV					Cl				
	Class 1	Class 2	Class 3	Class 4	Class 5	Class 1	Class 2	Class 3	Class 4	Class 5
AT 1				1					1	
AT 2					1				1	
AT 3					1			n.d.		
AT 4				1				1		
B 1		1							1	
B 2	1								1	
B 3				1			1			
B 5			n.d.							1
B 6				1			1			
B 7					1			1		
B 8	1									1
FIN 1				1			1			
GE 1		1						1		
GE 2				1				1		
GE 3				1			1			
GE 6							1			
IT 1			1						1	
IT 3			1					1		
N 1				1		1				
N 2				1			1			
N 3				1			1			
NL 1			1					1		
NL 2				1				1		
NL 3				1				1		
NL 4					1			1		
SE 1				1		1				
SE 2				1		1				
SE 3			1				1			
SE 4				1			1			
Sum	2	2	4	15	4	3	9	9	5	2

*based on sets of 10 data and given minimum for NCV- and given maximum for Cl-values of the classes
n.d.: class cannot be determined as values are out of range of the classification.

5.2.6 Boundaries of classes for Hg

The technology of the main users of SRF has been investigated with respect to the relationship between input and output of heavy metals. The developed transfer factors could be used for the calculation of maximum possible concentrations. The limit values of the Waste Incineration Directive comprised the basis for these calculations. Maxima of Hg varied from 0.028 mg/MJ for FBC till 0.33 mg/MJ for cement kilns on the assumption of 100% input of SRF.

However, these maxima may form an obstacle for the usage of e.g. fuels made of sewage sludge and filter cakes in cement kilns.

In practice the fuel mix predominates and not the maximum allowable concentration in one of the components in accordance with the requirements of the WID. The maximum limit for the concentration of Hg in SRF is related to the maximum allowable value for blending wastes (5-10 mg/kg d and ar) and the minimum NCV in practice, which gives a rounded down value of 1 mg/MJ for the 80th percentile.(see also annex 8)

In practice for rather homogeneous SRF`s the median values happen to be about 50% of the 80th percentile values of SRF. This fact has been used in the classification.

The boundaries of the classes were chosen taking into account the properties of the SRF`s on the one hand and the requirements of the users on the other hand. This leads to 5 classes for Hg shown in table 17. The highest class is reserved for SRF derived from e.g. sewage sludges and filter cakes (see also annex 8).

Table 17 Proposed Classes for Hg* (resolution Obourg 24 September 2004)

Classification Property	Designation	Unit	Classes				
			1	2	3	4	5**
Mercury	Hg	mg/MJ ar median 80th percentile	<i><=0,02</i>	<i><=0,03</i>	<i><=0,08</i>	<i><=0,15</i>	<i><=0,50</i>
			<i><=0,04</i>	<i><=0,06</i>	<i><=0,16</i>	<i><=0,30</i>	<i><=1,00</i>

* Values refer to a minimum of 10 analyses.

** For SRF with high ash content and therefore a higher raw material substitution in the clinker production, with a maximum of 10 mg/kg ar

An overview of the classification of SRF`s is shown in table 18. There are two methods which can be used for classification: When more than 10 assays are available the so called 50% rule can be applied. In this case the median and 80th percentile values of the assays have to meet 50% of the class boundaries. When more than 40 assays are available the random generator (see also annex 5 section 1.4) may be used, which takes at random sets of 10 assays from the dataset. If the share of passed datasets is > 95% for a class the SRF complies with that class. It turns out that the results obtained with the random generator are tending to lower classes or the same as those obtained using the 50% rule, which seems to result in a more conservative approach (marked italics). There is only one exception AT 2, which maybe due to extreme variations in the mixture of the input consisting of MSW fractions and sludge.

Table 18 shows that in about a third of the results the classes obtained with the random generator are higher than those when the median and 80th percentile of the complete data set were taken (column dataset). The use of only 10 assays for Hg causes strict classification because a producer of SRF who wants to be certain in meeting the class boundaries will at the utmost "use" 50% of the class maximum (see also figure 5 of annex 5). Table 18 also shows that both methods of classification are resulting in more conservative results compared to the complete data set (50% rule > random generator > complete data set).

Table 18 SRF's classified based on Hg content, influence of data collective and type of classification method on classification results

designation	50% rule median*0,5	80perc*.0,5	50% rule med./80perc.	random generator median/80perc. results Hg>95%	complete dataset median/80perc.
AT 2	3	3	3	5	3
AT 3	4	3	4	3	3
B 1	3	3	3	3	3
B 2	3	3	3	3	3
B 3	4	3	4		3
B 4	5	4	5		4
B 5	5	5	5	5	5
B 6	4	3	4	4	3
B 7	4	3	4		3
B 8	3	1	3		1
FIN 1	1	1	1		1
GE 1	1	1	1	1	1
GE 2	2	2	2	2	1
GE 3	3	3	3	3	2
GE 4	4	4	4	3	3
GE 5	5	5	5	4	4
GE 6	1	1	1	1	1
IT 1	3	3	3	2	1
IT 2	2	2	2		1
IT 3	3	3	3		2
N 1	1	1	1		1
N 2	1	1	1		1
N 3	3	3	3		2
NL 1	1	1	1		1
NL 2	2	2	2		1
NL 3	3	2	3	2	1
NL 4	5	4	5	4	4
NL 5	4	3	4		3
SE 1	1	1	1		1
SE 2	1	1	1	1	1
SE 3	2	1	2		1
SE 4	1	1	1	1	1

Italics, red: conservative classification compared to random generator
 Bold: conservative classification compared to complete data set

5.2.7 Boundaries of classes for Cd

Analogous to the procedure used with Hg the technology of the main users of SRF has been investigated on the relationship between input and output of heavy metals. The developed transfer factors could be used for the calculation of maximum possible concentrations. The limit values of the Waste Incineration Directive constituted the basis for these calculations. Maxima based on 80th percentile values of Cd+Tl varied from 0.25 mg/MJ for WBB till 85 mg/MJ for FBC with active coal flue gas cleaning equipment on the assumption of 100% input of SRF. The contribution of Tl is negligible and has not be taken into account, see annex 9.

The calculated maximum for cement kilns is 6.9 mg/MJ. This maximum may form an obstacle for the usage of e.g. fuels made of some sewage sludges and filter cakes in cement kilns, which is common practice.

In practice the fuel mix predominates and not the maximum allowable concentration in one of the components in accordance with the requirements of the WID. Also analogous to Hg the maximum limit in class 5 for the concentration of Cd in SRF is related to the maximum allowable value for blending wastes and the minimum NCV in practice, which gives a rounded down value of 30mg/MJ for the 80th percentile, see also annex 8.

The median values happen to be about 50% of the 80th percentile values for the more homogeneous SRF's. This fact has been used in the classification.

The boundaries of the classes were chosen taking into account the properties of the SRF's on the one hand and the requirements/the technical possibilities of the users on the other hand. This leads to 5 classes for Cd shown in table 19. The highest class is reserved for SRF derived from e.g. sewage sludges and filter cakes (see also annex 8).

Table 19 Proposed Classes for Cd

Classification property	Designation	Unit	Classes*				
			1	2	3	4	5**
Cadmium	Cd	mg/MJ ar	<=0,1	<=0,30	<=1,0	<=5,0	<=15
		median 80th percentile	<=0,2	<=0,60	<=2,0	<=10	<=30

* Values refer to a minimum of 10 analyses.

** For SRF with high ash content and therefore a higher raw material substitution in the clinker production with a maximum of 100 mg/kg ar

The values used to classify should rely on at least 10 consecutive data for practical reasons (including statistical significance). The number is a minimum for statistics and this number of data can be collected in a reasonable time

Table 20 shows the results of the classification using the random generator and the 50% rule. This rule turns out to be applicable for Cd as well. Analogous to Hg are the calculated classes higher or equal to those based on the median and 80th percentile of the complete data set (column dataset).

Table 20

SRF's classified based on Cd content (designation: codes are applied as confidential)

designation	50% rule		50% rule	random generator	complete dataset
	median*0,5	80perc*.0,5	med./80perc.	median/80perc. results Cd>95%	median/80perc.
AT 1	3	2	3	2	2
AT 2	3	3	3	3	3
AT 3	3	3	3	3	3
AT 4	2	2	2	1	1
B 1	1	1	1	1	1
B 2	1	1	1	1	1
B 3	3	2	3		2
B 4	4	3	4		3
B 5	4	3	4		3
B 6	3	2	3		2
B 7	3	3	3		3
B 8	2	2	2		2
FIN 1	1	1	1	1	1
GE 1	1	1	1	1	1
GE 2	1	1	1	1	1
GE 3	3	2	3	2	2
GE 4	2	2	2	1	1
GE 5	1	1	1	1	1
GE 6	1	2	2	1	1
IT 1	2	2	2	1	1
IT 2					
IT 3	2	1	2		1
N 1	1	1	1		1
N 2	1	1	1		1
N 3	1	1	1		1
NL 1	2	2	2		2
NL 2	1	1	1		1
NL 3	2	1	2		2
NL 4	3	2	3	2	2
SE 1	1	1	1		1
SE 2	1	1	1	1	1
SE 3	1	1	1		1
SE 4	1	1	1	1	1

Italics, red:

conservative classification compared to random generator

Bold:

conservative classification compared to complete data set

5.3 Environmental parameter

It has been suggested to combine the classes for Hg and Cd (and Tl) to create one environmental classification parameter. However, the added value seems low as in the classification Hg dominates or is equal to Cd in practically all cases as is shown in table 21. There are only two exceptions GE 6 and NL 1 (bold). In both cases the SRF has class 2 for Cd and class 1 for Hg. GE 6 has a higher class for Cd than the other waste wood derived SRF's N1, SE1 and SE2. The reason of the anomaly for NL 1 maybe the use of databases over divergent periods and the difficulties in the sampling of the coarse material (mean particle size 350 mm), which may have caused the abnormal high results and a higher number of outliers of Cd concentration found. In annex 9 it has been proposed to leave Tl out of the classification because of the negligible concentration which is usually below or near the detection limit.

Table 21 Overview class level of Hg – Cd, 50%-rule applied

designation	Hg	Cd
AT 1	n.a.	2
AT 2	3	3
AT 3	4	3
AT 4	n.a.	2
B 1	3	1
B 2	3	1
B 3	4	3
B 4	5	4
B 5	5	4
B 6	4	3
B 7	4	3
B 8	3	2
FIN 1	1	1
GE 1	1	1
GE 2	2	1
GE 3	3	3
GE 4	4	1
GE 5	5	1
GE 6	1	2
IT 1	3	2
IT 3	3	2
N 1	1	1
N 2	1	1
N 3	3	1
NL 1	1	2
NL 2	2	1
NL 3	3	2
NL 4	5	3
SE 1	1	1
SE 2	1	1
SE 3	2	1
SE 4	1	1

5.4 Classification methods

In practice a classification method has to be available, taking into account a limited number of analyses or limited space of time (compared to a complete data set or a production period of more than a year) to make a decision upon the class of a SRF.

In case of Hg (Cd) the random generator may be used, which simulates a stochastic selection i.e. of 10 assays and is as mentioned above an appropriate tool in case of more than 40 available assays. In order to have a quite reliable tool if more than 10 but less than 40 assays are available, the 50% rule was introduced by the authors of this report.

In case of NCV and CI 10 assays are required for the calculation of the mean value.

5.5 Recommendations

- 1. The recommended classification for NCV and CI is shown in table 15. It is not possible to have closed classes with minimum and maximum values. Therefore minimum (NCV) and maximum (CI) values are proposed for the classification.**
- 2. The environmental parameter may be represented by Hg since based on actual SRF data there is no added value provided by Cd and TI, because Hg data makes in almost all cases a higher or equal classification number than the Cd value of the same SRF. TI has no influence on the classification of Cd+TI because of relatively low value of TI.**
- 3. The recommended environmental parameter for classification is Hg as shown in table 17.**
- 4. When more than 10 measurement results of Hg (each on the quantity specified in the classification system) are available classification may be determined by comparing these results to 50% of the class limits (median and 80 percentile). When more than 40 measurement results are available, classification may be determined by comparing those results to the class limits (median and 80 percentile) using the random generator and associated 10 measurement results. In both cases all available measurement results shall be used in accordance with the statistical analysis standards.**
- 5. Compliance testing has to be done with 10 measurements. In case of NCV and CI the mean value is used, and in case of Hg the median and the 80th percentile.**

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7. ANNEXES

1. Main technologies and distribution of heavy metals

2. Transfer factors

3. Units chosen

4. Maximum possible concentrations of heavy metals in SRF

5. General analysis and evaluation of measured values of Solid Recovered Fuels

6. Overview of secondary fuel and SRF qualities

7. Heavy metals in SRF

8. Boundaries of classes

9. Thallium in SRF

Annex 1

Main technologies and distribution of heavy metals

The flow schemes for the main technologies involved are depicted in the figures 1 – 7.

The distribution of heavy metals over the output streams is influenced by the process properties. Especially the combustion temperature has a crucial influence on the concentration of heavy metals in the raw flue gases. The concentration of heavy metals in the cleaned flue gases depends on the gas cleaning system installed with or without using additives like activated carbon.

Table 1 **Combustion temperatures °C**

Cement	1800-2000
WBB	1400 – 1600 (hard coal)
DBB	1.000 – 1400 (brown coal 1000 – 1100)
FBC	900

Coal fired combustion plants:

WBB: wet bottom boiler (molten slag, power plant)

DBB: dry bottom boiler (dry slag, power plant)

FBC: fluidized bed combustion, mainly used for district heating

The process conditions in the cement and lime kilns result in an almost complete absorption of heavy metals in the product (clinker). The exceptions are the volatile elements Hg and Tl, although the transfer to the raw flue gas stream is relative low compared with the other technologies.

Pathway of heavy metals in cement kilns without preheaters (wet process)

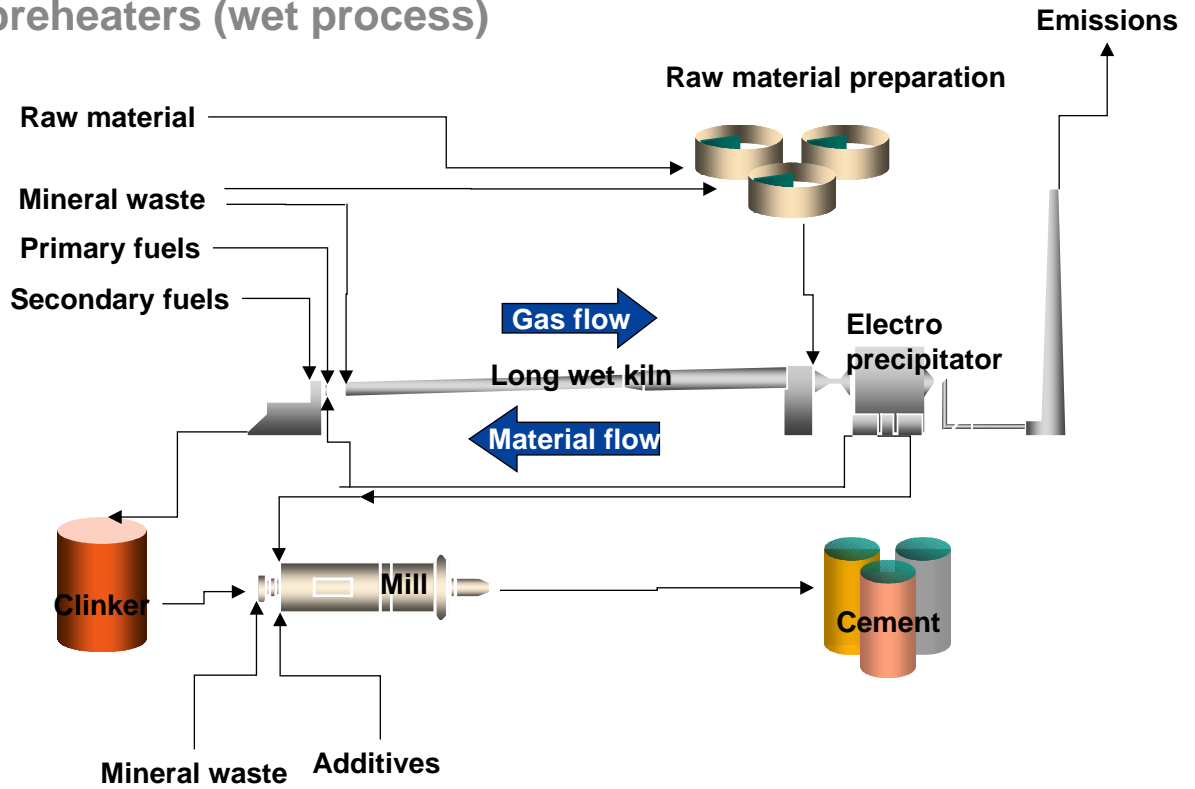
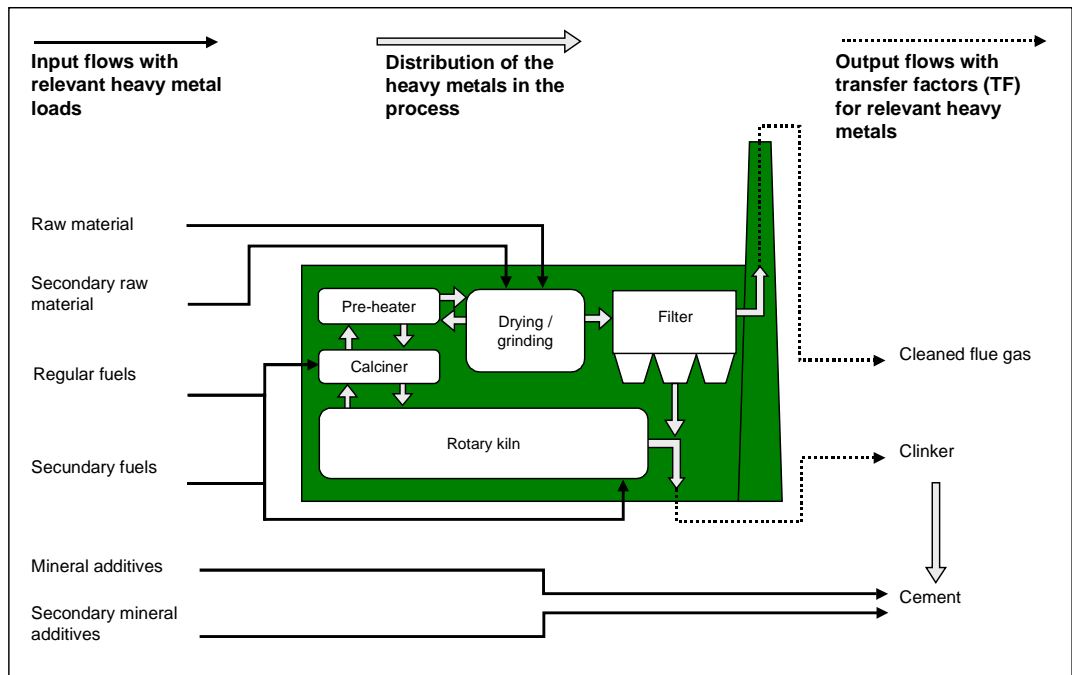


Figure 1

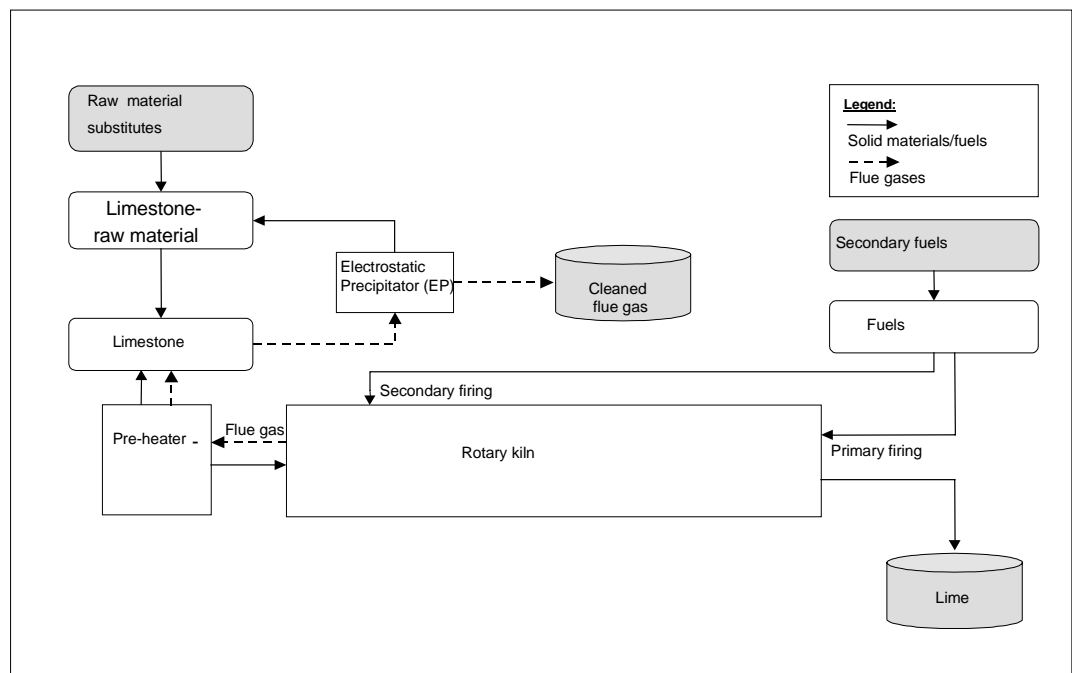
Pathway of heavy metals in cement kilns with preheaters (dry process)



Source: Prognos 5/2003

Figure 2

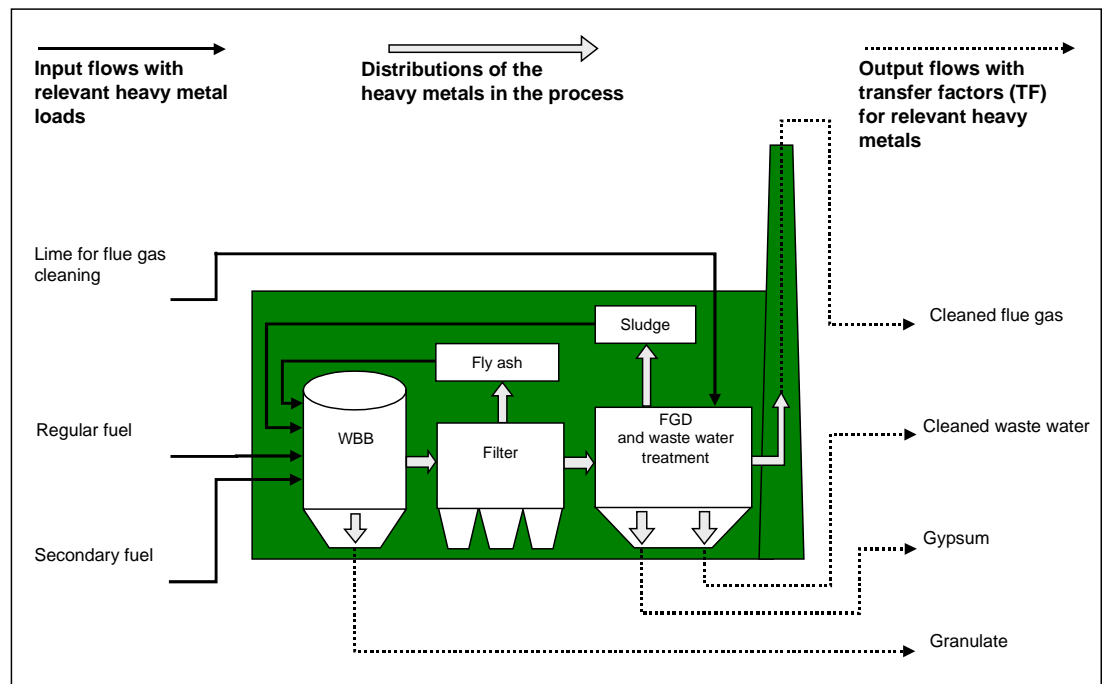
Pathway of heavy metals in lime kilns with preheater



Source: Prognos 5/2003

Figure 3

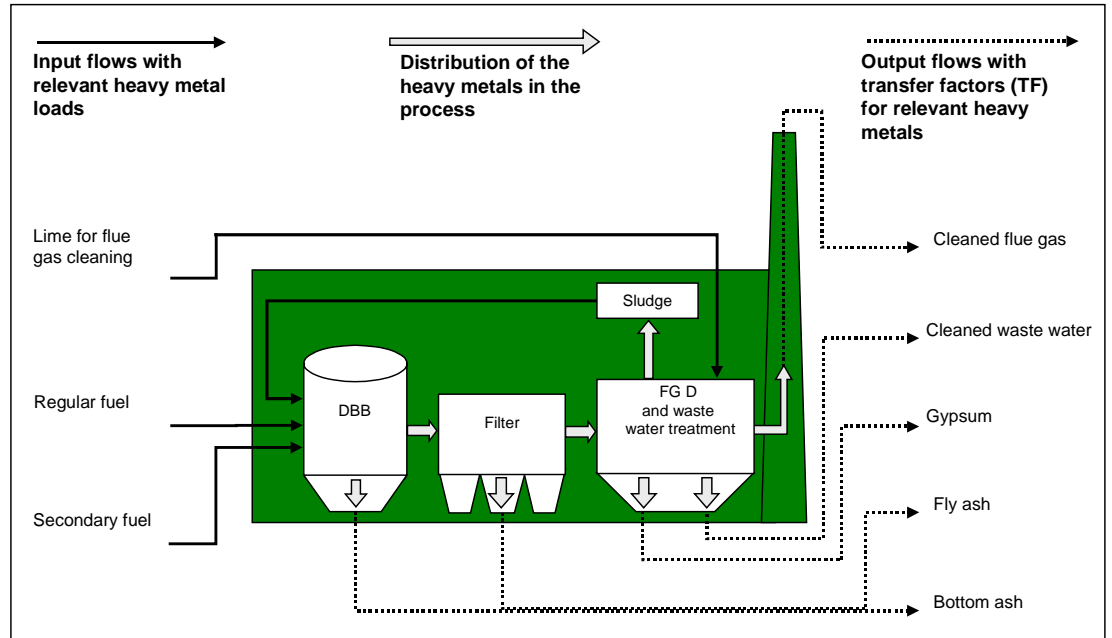
Pathway of heavy metals in Wet Bottom Boilers



Source: Prognos 5/2003

Figure 4

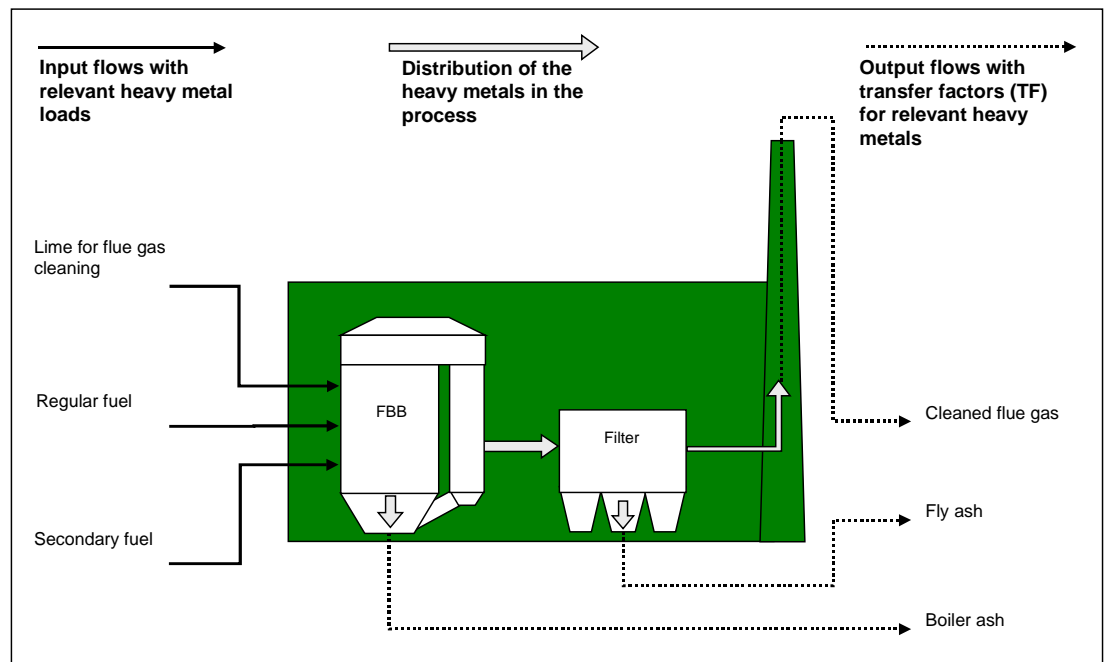
Pathway of heavy metals in Dry Bottom Boilers (hard coal and lignite)



Source: Prognos 5/2003

Figure 5

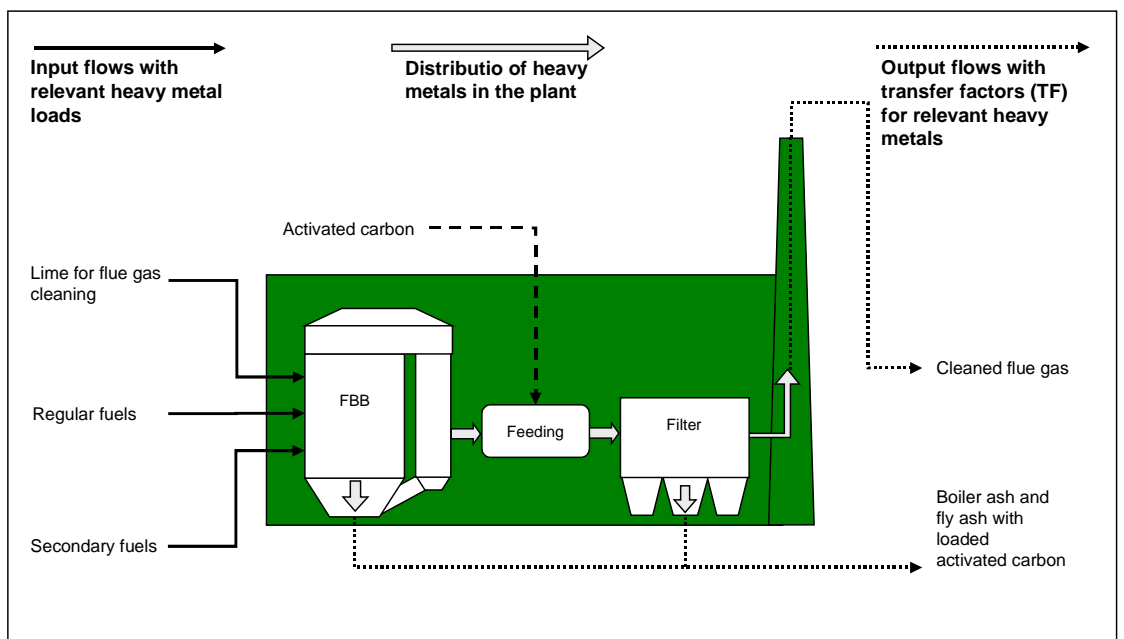
Pathway of heavy metals in Fluidized Bed Combustion



Source: Prognos 5/2003

Figure 6

Pathway of heavy metals in Fluidized Bed Combustion (Activated Carbon)



Source: Prognos 5/2003

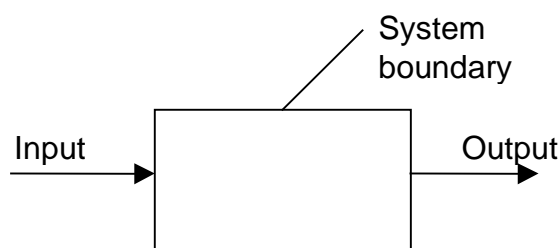
Figure 7

Annex 2

TRANSFER FACTORS

1. Use of transfer factors

The material flow analysis (MFA) was developed as a model for the material input and output flows of well defined systems /4/. Transfer factors (TF's) were introduced in 1999 /5/. These factors reflect the share of the input of a system that ends in a defined output. TF's are increasingly adopted in the assessment of mechanical treatment and thermal processes /6/.



The „transfer factor cleaned flue gas“ is the proportion of the input of a material in a process that is emitted in the air.

2. Use of material flow analysis (Example North Rhine Westphalia)

The MFA was introduced in NRW as an instrument for the assessment of the effects of waste derived fuels e.g. SRF in co-combustion. The method was introduced with a decree in October 2000 /7/. The aim of the decree is to assess the suitability of defined recovery processes for waste derived fuels with a well-known composition. Therefore the concentration of the properties mentioned in the German decree 17th BImSch are calculated and compared with the standards for incineration plants according to this decree.

An overview of the results descending from the practice of MFA is given in /8/ and /10/. The results show that industrial co-combustion may be a meaningful option, certainly for those waste derived fuels that meet the quality standards of RAL-GZ 724. See also table 1.

Table 1. Hg transfer factor %, cleaned fuel gases /10/

	<i>WBB</i> (hard coal)	<i>DBB</i> (hard coal)	<i>DBB</i> (lignite)
Model	50	26	20
Rentz	54	32	-
E.ON	55.6	9.9	-
Elektromark	31.9	-	-
RWE Power	-	26.8	-
RWE	-	-	14
Rheinbraun			

3. Possibilities and borderlines of such tools

The MFA offers the possibility to determine sensitive properties. Mercury may be mentioned that needs special attention in co-combustion processes concerning air-bound emissions due to its high volatility. The rather conservative approach applied in reference /8/ is disputed, as 90 percentile values regarding the composition of wastes and SRF are compared with mean values of coals. Therefore, the conclusion drawn that co-combustion would mean higher emissions is not confirmed in practice. Actual investigations show that fuels derived from wastes should be characterised by their median values /9/. The compliance with the daily mean values (emission standards) should be considered using mean realistic TF's. Recent research shows that TF's could vary substantially at a plant for a defined property. This means that the technology "power plants" cannot be sufficiently described with a single TF for each property. Therefore TF's were established for technical configurations specified by their firing and waste gas treatment systems /10/.

Annex 3

UNITS CHOSEN

1. NCV

The common unit used in practice is MJ/kg ar, this is why this unit is used in the classification system.

2. Cl

The usual unit is wt % either ar or d, with a slight majority in favour of ar. Arbitrarily the wt % d has been chosen as unit to be used in the classification system.

3. Hg and Cd

The common unit used in practice is mg/kg d. However, using this as a unit in a classification system without a link to the NCV or the substitution of raw materials, as implicitly is done in specifications, is irrational. There are two cases to be considered: SRF as fuel and SRF as a mixture of fuel and raw material.

3.1.1 SRF as fuel: mg/MJ

A combination of the units used for NCV and Hg gives the specific concentration mg/MJ. This unit makes it easy to compare Hg contents of different SRF's. In this way the problem is avoided in which at a certain limit for Hg, expressed in mg/kg, the concentrations in the flue gases are too high at low NCV or too strict at high NCV. See as an example table 1 for the influence of the unit chosen on the resulting output emission.

Using the practical data on the transfer factor (see annex 2 for background information) and the values of the WID for the several technologies the maximum concentration in the SRF may be calculated according to the formula

$$C_m = C_e \times V_s \times NCV \times 1/TF \quad (1)$$

or

$$C_s = C_e \times V_s \times 1/TF \quad (2)$$

C_m : concentration of a property in SRF [mg/kg ar], in practice the fuel mix

C_s : specific concentration of property in SRF mg/MJ ar

C_e : concentration of property in emitted gases mg/ m³, the maximum value from the WID is used.

V_s : specific volume of gas m³ /MJ ar

NCV: net calorific value MJ/kg ar

TF: transfer factor, depending on the technology applied for combustion and gas treatment and the plant performance.

Formula 2 has been used for the calculation of the maximum possible values of Hg in SRF.

Criticism has been expressed concerning the use of transfer factors and the values for the specific volume of gas. Naturally the specific volume of gas is influenced by the oxygen content and the C/H ratio of the SRF. The specific volumes used in section 2 rely on experience with SRF produced from MSW or from source-selected commercial wastes. The specific volume as a function of the fuel composition for power plants varies from 584 m³/MJ for coal (calculation based on C and 11% O₂) to 577 m³/MJ for biomass (calculation based on C₂H₄O₂ and 11% O₂, which means 389 m³/MJ for coal and 384 m³/MJ for biomass at 6% O₂). The value used for cement plants is based on the experience of cement plants. That value is highly influenced by the CO₂ from the calcination of the raw material.

These results elucidate that the proposed simplification for the values of the specific gas volume is appropriate.

For the variation in transfer factors see reference /10/. The data for Hg referring to WBB, DBB and brown coal plants from this reference are summarized in table 1 of annex 2.

3.2 SRF partly as raw material: mg/MJ and mg/kg

A credit is reasonable for the raw materials that are substituted having a SRF with high ash content. A possibility keeping the same units is to set limits relying on the lowest NCV used in practice and the maximum allowable Hg content in blending operations. This means that the units used in the classes remain mg/MJ with a maximum for the class with the highest values relying on the maximum allowable value for blending.

Table 1 Consequences of classifying fuels by pollutant expressed in different units

Material, Molecular structure	(Inert) ash content	Moisture	Composition of dry organic fraction				n_{et}	Flue gas volume 1)		Assumptions for Me limitation on input fuel and calculated resulting output emission 2)	
			C	H	N	O				0,4 mg/kg	0,03 mg/MJ
	%	%	%	%	%	%	MJ/kg	m ³ /kg	m ³ /MJ	mg/m ³	mg/m ³
Cellulose, 3) (C ₆ H ₁₀ O ₅) _n	0 11	0	44,4 39,5	6,2 5,5	- -	49,4 44,0	16,1	9,1	0.565	0,044	0.053
Polish coal, 3)	0 11		82,0 73	5,3 4,7	1,1 1,0	10,2 9,1					
Polyethylene, 3) (CH ₂) _n	0 11	0	86 85,1	14 12,5	- -	- -	43,0	24,2	0.563	0,016	0,053
Could be extended with “real” moist materials used as fuel											

Notes:

- 1) At 11 % excess oxygen in flue gas.
- 2) Metal (Me) is assumed to have a Transfer Factor (TF) 100, i.e. all goes as stack emission.
- 3) From CEN/TR 14745, Annex B, references 1) and 2) and CEN/CR 13686:2001, Annex A, Table 2.

Annex 4

MAXIMUM POSSIBLE CONCENTRATIONS OF HEAVY METALS IN SRF

1. Introduction

In the first resolution CEN/TC 343 WG 2 decided on three properties for heavy metals: Hg, Cd+Tl and the sum of the other heavy metals mentioned in the WID. It has been assumed that the maximum possible concentration of heavy metals in a SRF may be used to indicate the suitability for a technology. See also annex 7 table 5. The background of the calculations is described in annex 3. In its 3rd resolution the WG decided to focus on Hg as property relevant for the environmental aspects of heavy metals. However, the information on the other heavy metals is also given in tables 1-6 of this annex.

2. Cement industry

In the cement industry mainly Hg is relevant as to emission. The other heavy metals are almost completely incorporated in the clinker. The transfer factor is mainly based on practical data from plants in Belgium and Germany /2,10/.

Table 1 Maximum possible concentrations in SRF, cement kiln wet process

	<i>TF</i>	<i>C_e (WID)mg/m³</i>	<i>C max mg/MJ ar (calculated)</i>
Hg	0.2000	0.05	0.17
Cd + Tl	0.0048	0.05	6.90
Sum HM	0.0002	0.50	1650

Notes: 1. V_s 0.66 m³/MJ
2. C_e at 10% O₂
3. There is a substantial contribution to raw material substitution at higher concentrations of minerals (ash). This also means that emissions originated from raw materials may be substituted by (other) emissions from the SRF. The presentation of the emission level in mg/MJ does not account for this phenomenon and is not appropriate for fuels having a high ash content and at the same time a low NCV.

Table 2 Maximum possible concentrations in SRF, cement kiln dry process

	<i>TF</i>	<i>C_e (WID)mg/m³</i>	<i>C max mg/MJ ar (calculated)</i>
Hg	0.1- 0.4	0.05	0.082 – 0.33
Cd + Tl	0.0048	0.05	6.90
Sum HM	0.0002	0.50	1650

Notes: 1. V_s 0.66 m³/MJ
2. C_e at 10% O₂
3. See note 3 of table 5

3. Coal fired power plants

Transfer factors differ for the several technologies. The values are based on investigations in Germany /10/. Dutch experience is limited to plants with the dry ash system /11/. The values correspond for Hg to the German for the same technology. Differences exist for Cd and Sb. The Dutch TF are 4 (Cd) –6 (Sb) times lower.

Table 3 Maximum possible concentrations in SRF, DBB Hard Coal

	<i>TF</i>	<i>Ce (WID) mg/m³</i>	<i>C max mg/MJ ar</i>
Hg	0.26	0.05	0.065
Cd+Tl	0.014	0.05	1.21
Sum HM	0.0016	0.50	106

Notes: 1. Vs 0.34 m³/MJ
 2. Ce at 6 % O₂
 3. TF value calculated (weighted average) based on average composition of SRF produced from high calorific fraction of MSW.

Table 4 Maximum possible concentrations in SRF, WBB Hard coal

	<i>TF</i>	<i>Ce (WID) mg/m³</i>	<i>C max mg/MJ ar</i>
Hg	0.5	0.05	0.034
Cd+Tl	0.067	0.05	0.25
Sum HM	0.005	0.50	34.00

Notes: 1. Vs 0.34 m³/MJ
 2. Ce at 6 % O₂
 3. TF value calculated (weighted average) based on average composition of SRF produced from high calorific fraction of MSW
 4. The actual data base for TF of WBB is rather limited. Additional information may be expected in the near future as a result of actual use of SRF.

Table 5 Maximum possible concentrations in SRF, DBB Brown Coal

	<i>TF</i>	<i>Ce (WID) mg/m³</i>	<i>max mg/MJ ar</i>
Hg	0.2	0.05	0.085
Cd +Tl	0.04	0.05	0.43
Sum HM	0.001	0.5	170

Notes: 1. Vs 0.34 m³/MJ
 2. Ce at 6 % O₂
 3. TF value calculated (weighted average) based on average composition of SRF produced from high calorific fraction of MSW

4. FBC

Transfer factor values are based on investigations in Germany.

Table 6 Maximum possible concentrations in SRF, FBC

	<i>TF</i>	<i>TF(AC)*</i>	<i>Ce (WID) mg/m³</i>	<i>max mg/MJar</i>	<i>max mg/MJar (AC)*</i>
Hg	0.6	0.065	0.05	0.028	0.26
Cd+Tl	0.027	0.0002	0.05	0.63	85.
Sum HM	0.010	0.0002	0.50	17.00	850

Notes: 1. Vs 0.34 m³/MJ
 2. Ce at 6 % O₂
 3. TF value calculated (weighted average) based on average composition of SRF produced from high calorific fraction of MSW.
 * Systems using activated carbon (AC).

Annex 5

1. GENERAL ANALYSIS AND EVALUATION OF MEASURED VALUES of Hg and Cd in SOLID RECOVERED FUELS

The outcome of the round robin, organized by the Bundesgütegemeinschaft Sekundärbrennstoffe e. V., indicates that even with established protocols for sampling, sample preparation and analysis, substantial ranges occur for the analytical results. Reasons are i.e. that the property to be analyzed is not even distributed over all components in the SRF. Fine particles from e.g. metals and PVC may cause high values in the analytical result. Then the outcome does not give a representation of the quality of the SRF that has been sampled. Therefore single analytical results cannot be used in the assessment of the absolute maximum value. Which means that only a series of data can be applied for that purpose.

However, using a large series of data is not an applicable solution to this problem. There is a need for an appropriate method within the scope of the quality assurance and certification of SRF keeping in mind, limited resources and time for the collecting of data.

1.1 Distribution of the analytical values

The main part of the analytical data of SRF concerning heavy metals is usually in the lower range and scatter one-sided in the upper range. Usually the distribution of analytical data has right skewness for properties of waste as shows e.g. figure 1 for Hg, the detection limit representing the lowest values. On the other hand there is no limit for the maximum value.

The distribution of Hg data from high calorific fractions of MSW is shown in the figures 1 and 2. The transformed data (logarithm taken of the data) approximately indicate a normal distribution (Lognormal distribution, [Sachs, 1999] example taken from [Flamme, 2002]). Figure 3 shows an example of the distribution of Cd.

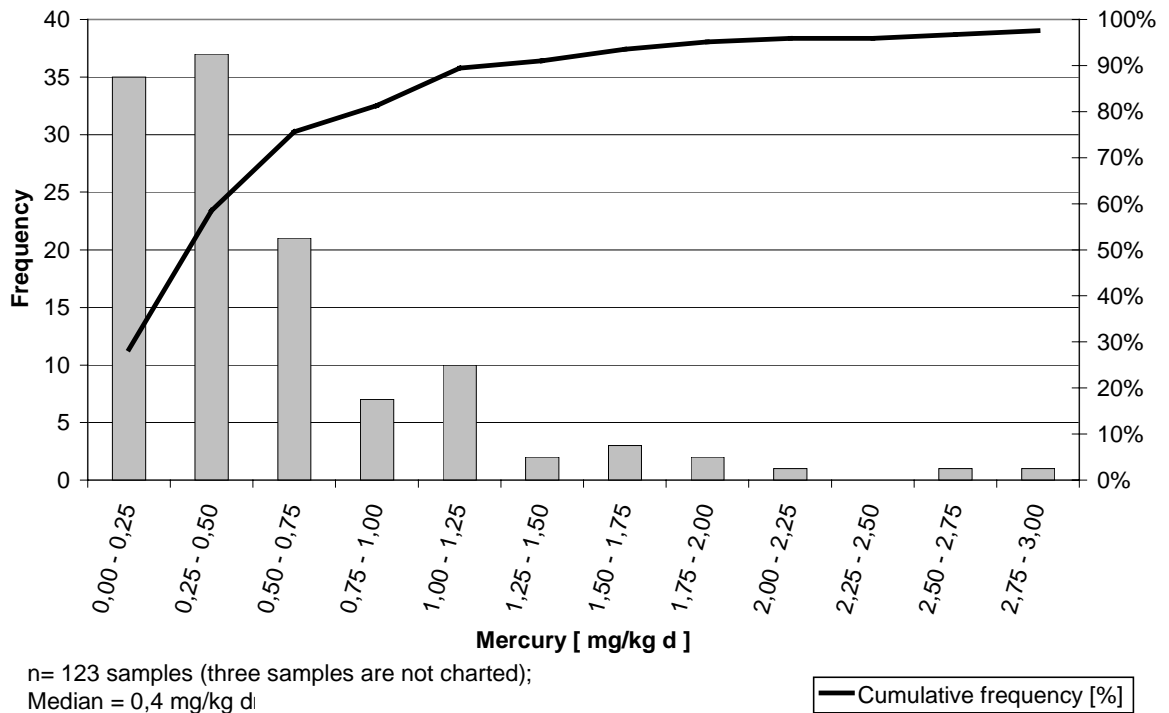


Figure 1: distribution of the Hg data of processed high calorific fraction of MSW

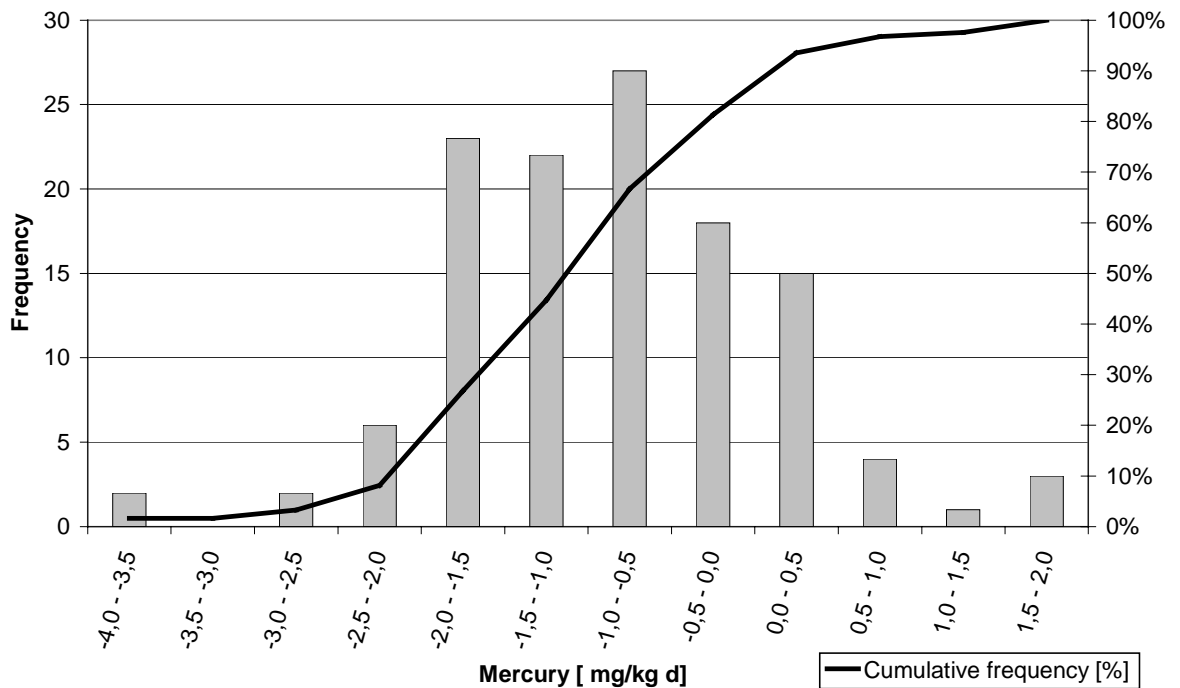


Figure 2: distribution of the transformed Hg data of processed high calorific fraction of MSW

The original values of the upper concentration range usually appear in the customary spectrum of the lognormal distribution for the measured values. Therefore they cannot be crossed out from the set of data. These values are not outliers as they are part of the lognormal distribution, see also figure 2. These distributions are determined by the uneven distribution of the property to be analysed over all components in the SRF. A normal distribution in many points may be expected if the property to be analysed is almost evenly distributed over all particles in the SRF (figure 4, SRF NL 4 shows an almost normal distribution) Note: However, the distribution of the data shown in figure 4 is lognormal according to the statistical calculations carried out by INFA using the KSA test.

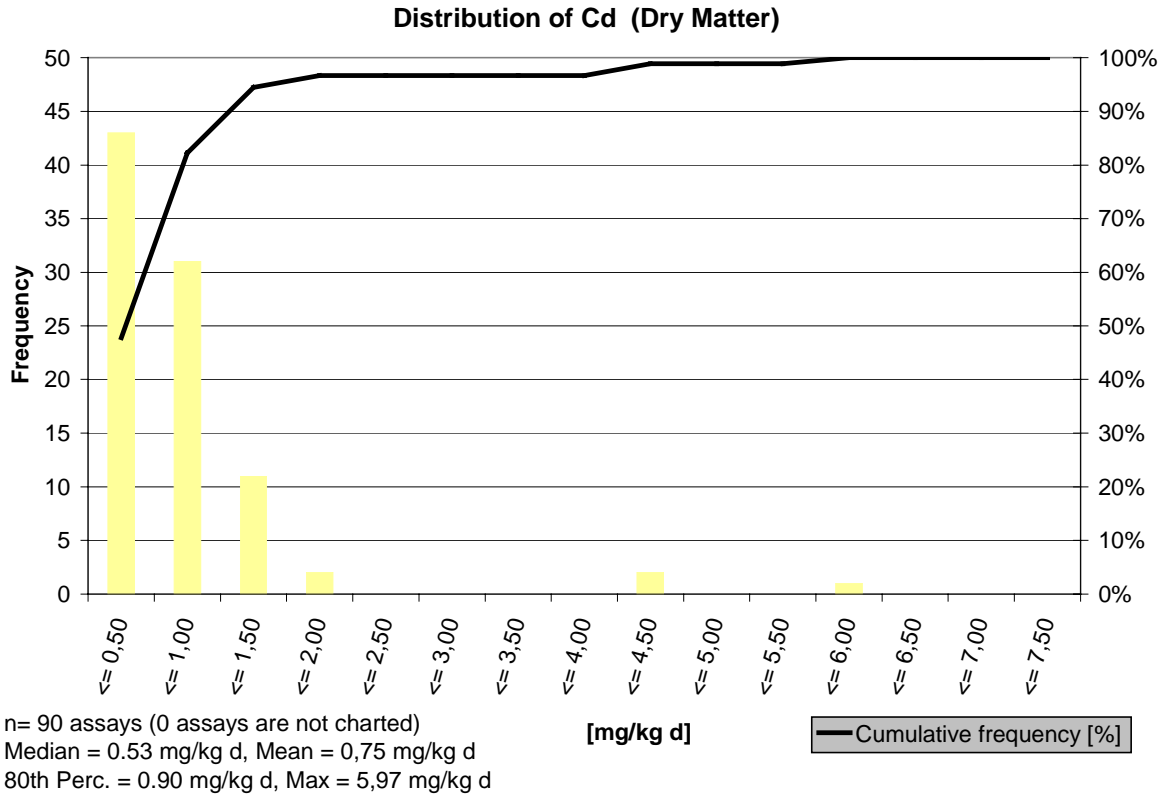


Figure 3: distribution of the Cd data of SE 4

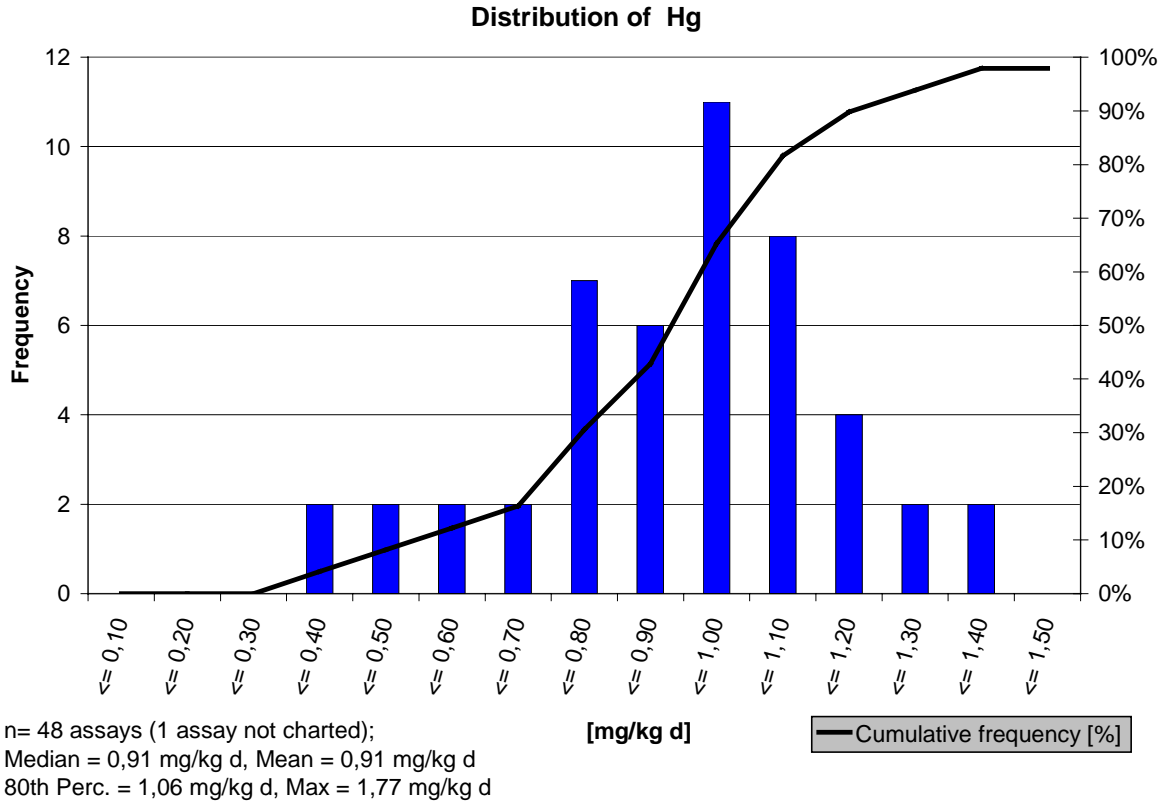


Figure 4: distribution of the Hg data of NL 4

1.2 Determination of the average concentration from analytical data of SRF

The average values of wastes can be determined using the measure of location. The measure of location of the normal distribution, the arithmetic mean is not appropriate for the determination of the average because of the asymmetrical right skewed distribution that occurs with the data of the heavy metal concentration in SRF. Then the average value will be influenced strongly by the far right situated values. In that case a geometric mean would be more appropriate.

However, lognormal distributions are not always dealt with. Therefore a central value independent from the type of distribution, the median, is required. Additionally, it is often necessary to determine the average based on a limited number of data (e.g. 10). The median is preferred for the determination of the mean concentration of a property because of its robustness and the independency of far right located values. The median and arithmetic mean are nearly identical in case of a normal distribution.

As the median value is the more appropriate description of the characteristic level of SRF's. It should be used for the calculation of emission relevant loads. See also tables 3 and 5 for a comparison of mean, median and geometric mean values.

1.3 Determination of the maximum concentration from the analytical data of SRF

Usually the content of a property of SRF is not only characterised by the average value but also by an upper value. From the observations concerning the distribution it can be concluded that the absolute maximum represents a random value. However, it is appropriate having a second statistical measure for the characterisation of the maximum value in SRF, which gives an indication of the range for the upper concentrations. The upper concentration range should be indicated with the 80th percentile of a distribution. The 80th percentile represents a value that is independent of the type of the distribution. The following table 1 summarises the assessment of different statistical methods.

Table 1: Assessment of different statistical methods with respect to SRF's

Different methods	pros	cons
median + 80th percentile	Independent of distribution, robust to „outliers“ Only median is not sufficient to consider the range of values determined, therefore 80th percentile to be considered as well to account for the upper values Easy determination With 10 values, declaration is possible Limit values can be established Indicator for heterogeneity of the SRF through the ratio 80th percentile/median With a normal distribution, median and mean value are nearly identical	Peak values are not considered, (<i>Note: There are indications for very large ranges with heterogeneous wastes, caused by fine particles from e.g. metals or PVC that end up in the analytic sample and influence the analytical outcome. However, this result does not represent the quality of the sampled SRF .</i>)
mean value + confidence interval	All data are considered in the evaluation load relevant „outliers“ are considered (<i>however see also at the top right</i>)	normal distribution as basis (note: analytic data often show a log normal distribution) mean value significantly influenced by peak values limit values cannot be established, at best a confidence interval can be chosen larger number of data are required for a confident result outlier test necessary

1.4 Minimum and maximum of median

In practice the number of data used for the calculation of the median is limited to e.g. 10, because of limited resources and time. This has consequences for the compliance with boundaries of classes. Figure 5 shows the range of the confidence interval of the median based on a range from 10 to 158 values for mercury in a SRF. The graph has been developed with a random generator. At random, 200 times series of analytical data of 10 to 158 were taken. Then the median was calculated at a confidence interval of 95%. The minimum and the maximum values for the median are shown in figure 5.

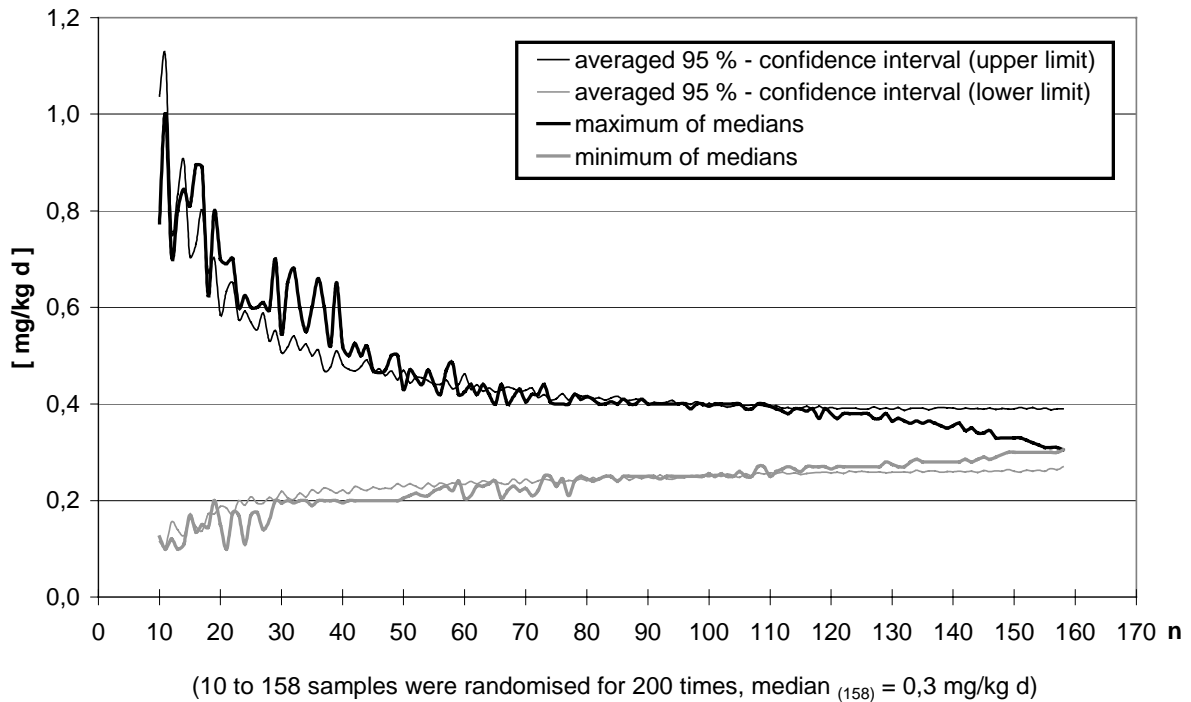


Figure 5: minimum value and maximum value for the median as well as the accompanying confidence interval (95%) for mercury at different sizes of one series of data for SRF

With 10 values the median for mercury in a SRF varies from 0.1 to 1.0 mg/kg d, but the median is 0.3 mg/kg over the whole series of values (30% of the maximum median of 10 values).

2. Specific analysis and evaluation of delivered data of Solid Recovered Fuels

2.1 Mercury

For the documentation of the Hg distribution in SRF data 29 records were collected from 5 Member States and Norway. The tables 2a and 2b are presenting the boundary conditions of the SRF data and the type of distribution.

Special attention was paid to those SRF that are significant concerning production and use now. Of each SRF 10 till 707 analytical data were made available resulting in a total number of analyses of 2459.

Input materials for these SRF's differ considerably, and varies from the SRF-production based on selected production wastes till different types of high calorific fractions.

Due to lacking uniform sampling methods for SRF the methods vary considerably. Partly national protocols or recommended procedures were used like RAL-GZ-724 or SFS 5875.

The analytical detection limits also differ considerably due to the different analytical techniques applied and the requirements of the users of SRF. They vary from 0.01 till 1.0 mg/kg d.

However, in spite of these differences in the conditions of input materials (sampling, sample preparation and analytical methods) common properties in the distribution of Hg can be derived for various SRF.

Generally a right skewed distribution occurs for Hg. The skewed distribution is more significant with a growing amount of data. A reduced analytical detection limit of 0.2 mg/kg also turns into more significant skewed distributions (see figures 6 and 7).

Table 3 shows the statistical outcome for the presented SRF's.

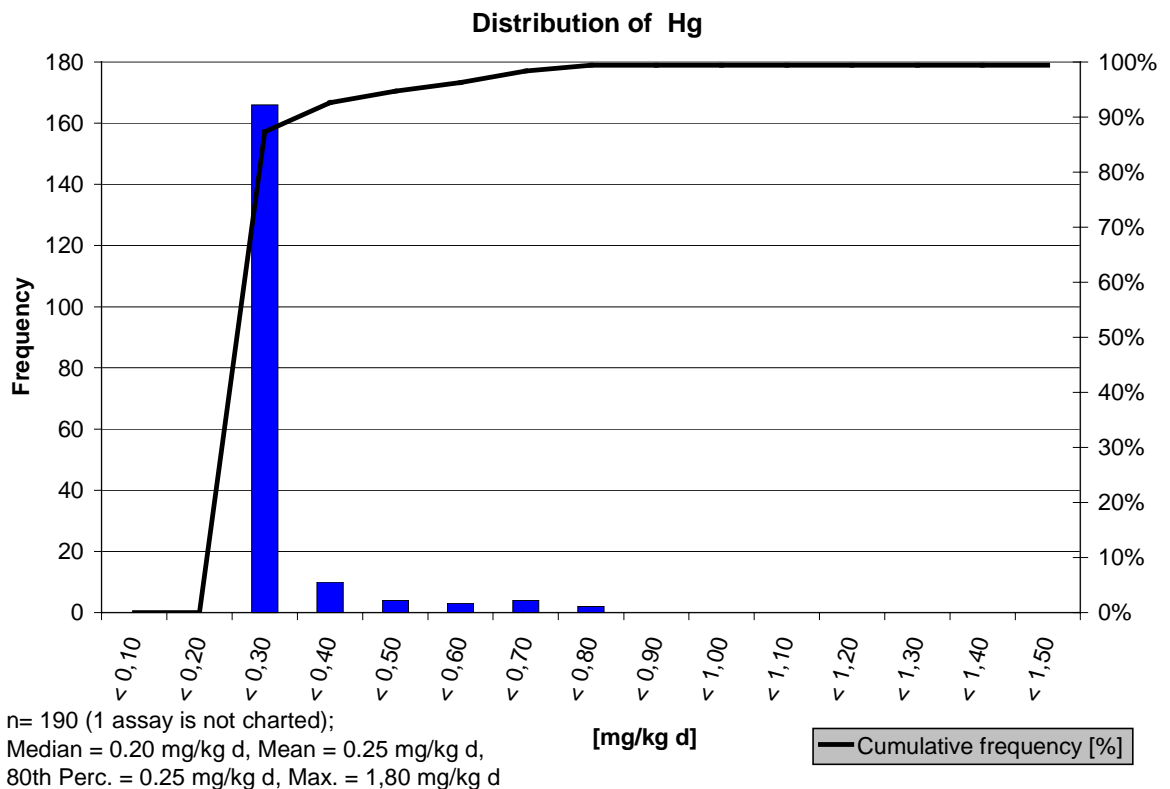


Figure 6: the distribution of the Hg data of GE 1

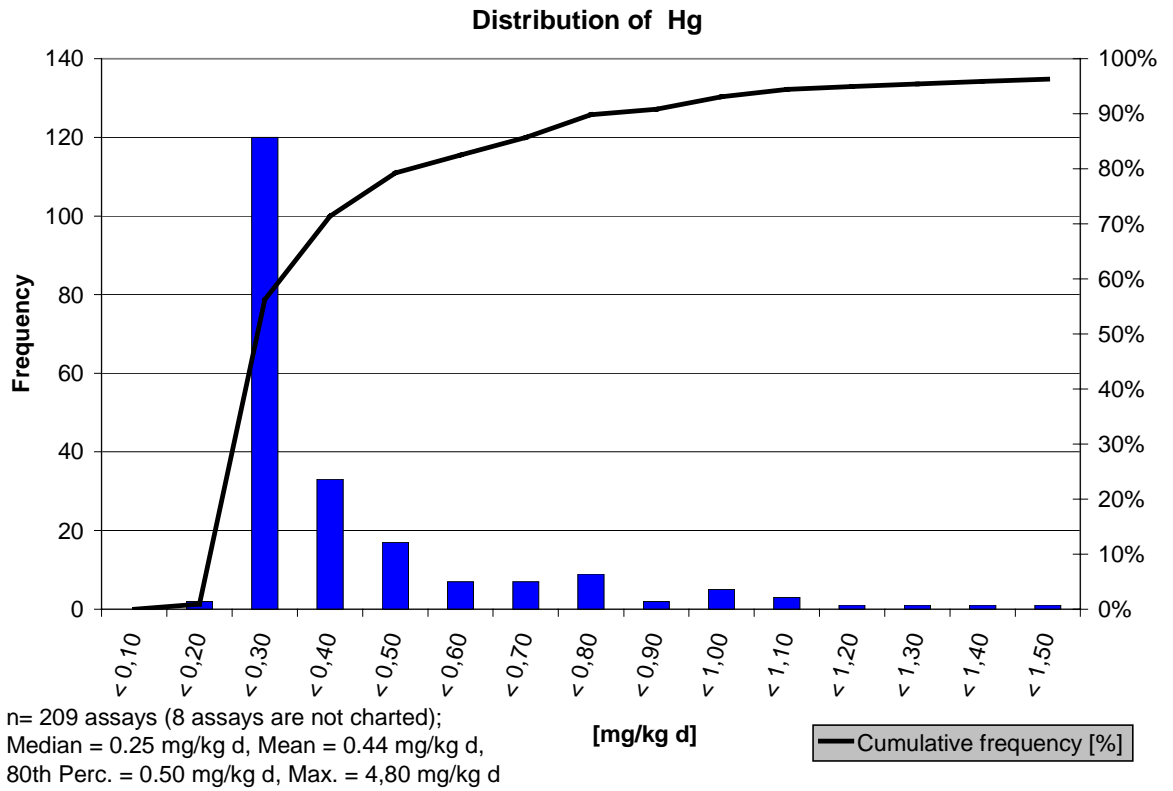


Figure 7: the distribution of the Hg data of GE 2

Table 2a: overview about boundary conditions of SRF- Hg data

	Designation	Origin of waste	sampling method	sample preparation	analysing method	standard for analysing method	detection limit mg/kg d
Austria	AT 2	MSW+sludge	n.a	n.a.	AAS	Onorm EN 1483	n.a.
	AT 3	MSW+sludge	n.a.	n.a.	AAS	Onorm EN 1483	n.a.
Belgium	B 1	select.com. waste	1)	1)	AAS	DIN 38406-E22-88	1 11)
	B 2	select.com. waste	1)	1)	AAS	DIN 38406-E22-88	1 11)
	B 3	filter cake	2)	2)	AAS	9)	0.5 ar 12)
	B 4	filter cake	2)	2)	AAS	9)	0.5 ar 12)
	B 5	filter cake	2)	2)	AAS	9)	0.5 ar 12)
	B 6	wood,sludge,act.carbon	2)	2)	AAS	9)	0.5 ar 12)
	B 7	resins,act.carbon,bleach.earth	2)	2)	AAS	9)	0.5 ar 12)
	B 8	polymers	2)	2)	AAS	9)	0.5 ar 12)
Finland	FIN 1	source select.MSW	SFS 5875 3)	SFS 5875	AAS	SFS 5229 (ENV 13370)	0.1-0.2
Germany	GE 1	select.com. waste	RAL-GZ 724 4)	RAL-GZ 724	AAS	DIN EN 12338-5	0.2
	GE 2	MSW	RAL-GZ 724 4)	RAL-GZ 724	AAS	DIN EN 12338-5	0.2
	GE 3	MSW	n.a.	n.a.	n.a.	n.a.	n.a.
	GE 4	munic.sludge	n.a.	n.a.	AAS	DIN EN 12338-5	n.a.
	GE 5	munic.sludge	n.a.	n.a.	AAS	DIN EN 12338-5	n.a.
	GE 6	demol.wood	n.a.	n.a.	AAS	DIN EN 12338-5	0,03
Italy	IT 1	MSW	UNI 9903-3 5)	UNI9903-3/12 5)	GF-AAS	ISO	0.01
	IT 2	MSW	n.a.	n.a.	n.a.	n.a.	n.a.
	IT 3	MSW	UNI 9903-3 5)	UNI9903-3/12 5)	GF-AAS	ISO	0.01
Norway	N 1	demol.wood	SS 187113	n.a.	ICP-AES	EPA 200.7	0.01-0.02
	N 2	select.com.waste	SS 187113	n.a.	ICP-AES	EPA 200.7	0.01
	N 3	light ind./com.waste	10)	n.a.	AAS	NF EN 1483	0.5-1.1 13)
Netherlands	NL 1	MSW	6)	6)	AAS	DIN EN 12338-5	0.2
	NL 2	MSW	6)	6)	AAS	DIN EN 12338-5	0.2
	NL 3	MSW	6)	6)	AAS	DIN EN 12338-5	0.2
	NL 4	MSW(WOF)	7)	7)	AAS	NTA 8200	0.2
	NL 5	munic.sludge	n.a.	n.a.	AAS	DIN EN 12338-5	n.a.
Sweden	SE 1	waste wood	8)	8)	ICP-AES	EPA 200.7	0.01
	SE 2	waste wood	8)	8)	ICP-AES	EPA 200.7	0.01
	SE 3	select.com. waste	8)	8)	ICP-AES	EPA 200.7	0.01
	SE 4	select.com. waste	8)	8)	ICP-AES	EPA 200.7	0.01
Total/Average							

n.a.: not available

1) Each shift a sample of about 1kg. Samples per day are mixed. Two analytic samples are produced by shredding: coarse 2 mm and fine 1mm (used for metal analysis).

2) 6-8 increments/truck are mixed, about 2 kg/truck, daily samples mixed to 2 kg, daily samples mixed to week sample, size reduction to < 0,5 mm analysis(one sample corresponds to 300-500 ton).

3) 12 mm size material; sampling method: from conveyor belt, 3 increments/day of a few l, month sample reduced to 10 liter and send to laboratory

4) sampling per 500 tons 250 l (5l every 10 tons), store 10 l, 10 l for analysis, reduce size < 1mm

5) 35 increments /sample, 2,4 kg/sample for 40 mm material, reduction to 1 mm for analysis

6) sampling per day 250 l, size reduction < 40 mm, store 12.5 l and dry; per week mix daily samples, store 15 l; per 4 weeks , mix week samples, reduce size < 1mm and send to laboratory

7) sampling per day 90 l, size reduction < 40 mm, store 10 l and dry; per week mix daily samples, store 10 l; per 4 weeks mix week samples, reduce size to < 1mm and send to laboratory

8) truck, wood chips: 1 sample/truck from 5 increments, 1 sample/month /supplier composed of truck samples; truck, fluff: 1 sample/month composed of 1 increment/truck; ship: 4 lot samples/ship composed of increments taken every 20 minutes. The lot samples are mixed to a laboratory sample.

9) Round Robin with 54 laboratories

10) 1 increment/day (2 kg), 10 increment are mixed to a sample. Size reduction to < 1mm for the laboratory sample.

11) specifications of users does not require lower d.l.

12) ar

13) laboratory of producer 17 assays, others n.a.

Table 2b: overview about boundary conditions and Hg-distribution of SRF-data

1): in brackets when the number of data is < 40

2): detection limit at other laboratory 0.05-0.06 mg/kg. However all data are considered with dl of 0.2 mg/kg.

Designation	number of analyses	number of analyses < detection limit	share of analyses with value <detection limit	number of values >....	share of analyses not charted	period of data	kind of distribution 1) <i>calculation/optical evaluation</i>
AT 2	54	0	0%	6/1.5	11%	10/2001	skewness right
AT 3	56	0	0%	5/1.5	9%	8/2003	log normal
B 1	67	57	85%	0 / 4,5	0%	1/2003-6/2003	skewness right
B 2	57	42	74%	0 / 4,5	0%	1/2003-6/2003	skewness right
B 3	30	24	80%	0 / 10	0%	2003-7/2004	(skewness right)
B 4	44	39	89%	0 / 10	0%	2003-7/2004	skewness right
B 5	64	52	81%	0 / 10	0%	2003-7/2004	skewness right
B 6	707	554	78%	4 / 10	1%	2003-7/2004	skewness right
B 7	11	11	100%	0 / 10	0%	2003-7/2004	not evaluable
B 8	42	42	100%	0 / 10	0%	2003-7/2004	not evaluable
FIN 1	42	7	17%	1 / 1.5	2%	3/1998-4/2003	skewness right
GE 1	190	127	67%	1 / 1.5	0%	1/2002-9/2003	skewness right
GE 2	209	93	44%	8 / 1.5	4%	1/2002-9/2003	skewness right
GE 3	70	n.a.	n.a.	0/1.5	0%	n.a.	lognormal
GE 4	178	n.a.	n.a.	10/1.5	6%	1/1998-12/1998	skewness right
GE 5	178	n.a.	n.a.	10/1.5	6%	1/1998-12/1998	skewness right
GE 6	65	28	43%	0/1.5	0%	6/1994-1/1998	skewness right
IT 1	62	0	0%	0 / 1.5	0%	2/2001-7/2003	skewness right
IT 2	13	n.a.	n.a.	1 / 1.5	8%	2001-2002	(lognormal)
IT 3	13	0	0%	1/1.5	8%	1/2003-3/2004	(log normal)
N 1	20	2	10%	0/1.5	0%	2002-2004	(skewness right)
N 2	25	0	0%	0/1.5	0%	2002-2004	(skewness right)
N 3	31	n.a.	n.a.	1/1.5	3%	9/2003-5/2004	(skewness right)
NL 1	22	18 2)	82%	0 / 1.5	0%	1/2002-8/2003	(skewness right)
NL 2	22	2	9%	4 / 1.5	14%	1/2002-8/2003	(skewness right)
NL 3	42	20	48%	0/1.5	0%	1998 - 2001	lognormal
NL 4	42	0	0%	1 / 1.5	2%	9/2002-8/2003	lognormal
NL 5 sludge	21	0	0%	0 / 1.5	0%	n.a.	(skewness right)
SE 1	28	0	0%	1/1.5	4%	7/2002-1/2004	(skewness right)
SE 2	117	7	6%	1/1.5	1%	7/2002-1/2004	log normal
SE 3	17	0	0%	0/1.5	0	7/2002-1/2004	(skewness right)
SE 4	90	0	0%	1/1.5	1%	7/2002-1/2004	skewness right
	2629	1125	43%		2%		

Table 3: overview about statistical outcome of the represented SRF`s for Hg

100% of dl has been taken

Designation	median mg/kg d	arithmetic mean mg/kg d	80th perc. mg/kg d	90th perc. mg/kg d	maximum mg/kg d	standard deviation mg/kg d	rel. standard deviation mg/kg d	ratio 80./50. perc.	geometric mean mg/kg d
AT 2	0,51	1,31	0,688	3,58	13,89	2,513	192%	1,35	0,65
AT 3	0,71	0,766	0,958	1,29	2,51	0,482	63%	1,35	0,65
B 1	1,00	1,24	1,00	2,00	4,00	0,63	51%	1,00	1,15
B 2	1,00	1,33	2,00	2,00	4,00	0,64	48%	2,00	1,23
B 3	0,70	0,90	0,80	1,73	2,30	0,52	58%	1,14	0,80
B 4	0,90	1,30	0,94	2,00	5,30	1,17	90%	1,04	1,12
B 5	1,90	3,00	1,92	5,90	16,10	2,61	87%	1,01	2,44
B 6	0,70	1,50	0,69	2,61	67,30	3,37	225%	0,99	0,91
B 7	0,60	0,60	0,62	0,62	0,60	0,00	0%	1,03	0,62
B 8	0,50	0,50	0,50	0,50	0,50	0,00	0%	1,00	0,50
FIN 1	0,20	0,36	0,27	0,31	7,50	1,13	313%	1,37	0,18
GE 1	0,20	0,24	0,21	0,33	1,80	0,15	64%	1,05	0,22
GE 2	0,25	0,44	0,50	0,81	4,80	0,56	128%	2,00	0,32
GE 3	0,43	0,47	0,57	0,64	1,10	0,15	33%	1,33	0,45
GE 4 (sludge 10)	0,49	0,66	0,90	1,10	5,50	0,66	100%	1,84	0,51
GE 5 (sludge 70)	0,49	0,66	0,90	1,10	5,50	0,66	100%	1,84	0,51
GE 6 (wood)	0,09	0,14	0,20	0,27	0,55	0,11	80%	2,22	0,10
IT 1	0,40	0,45	0,67	0,92	1,16	0,29	63%	1,70	0,35
IT 2	0,23	0,54	0,84	1,00	2,80	0,75	139%	3,65	0,29
IT 3	0,46	0,62	0,94	1,24	1,70	0,47	75%	2,04	0,49
N 1	0,12	0,13	0,2	0,32	0,49	0,13	102%	1,71	0,07
N 2	0,21	0,28	0,35	0,59	0,91	0,21	77%	1,68	0,21
N 3	0,5	0,56	0,9	0,98	1,85	0,4	71%	1,80	0,44
NL 1	0,20	0,20	0,20	0,33	0,61	0,14	71%	1,00	0,16
NL 2	0,28	0,49	0,56	1,47	1,79	0,53	108%	2,00	0,33
NL 3	0,36	0,37	0,54	0,69	1,13	0,25	68%	1,50	0,28
NL 4	0,92	0,92	1,10	1,22	1,77	0,27	29%	1,20	0,88
NL 5	0,68	0,70	0,78	0,82	1,00	0,11	16%	1,15	0,69
SE 1	0,12	0,39	0,36	0,63	5,49	1,02	264%	3,13	0,15
SE 2	0,05	0,07	0,08	0,12	0,39	0,07	100%	1,79	0,05
SE 3	0,24	0,26	0,28	0,34	0,41	0,07	27%	1,16	0,25
SE 4	0,13	0,20	0,21	0,26	4,29	0,45	220%	1,53	0,14
Total/Average	0,49	0,67	0,68	1,18	5,28	0,64	96%	1,58	0,54

2.2 Cadmium

For the documentation of the Cd distribution in SRF data 26 records were collected from 5 Member States and Norway. The tables 4a and 4b are presenting the boundary conditions of the SRF data and the type of distribution.

Special attention was paid to those SRF that are significant concerning production and use now. Of each SRF 10 till 178 analytical data were made available resulting in a total number of analyses of 1248.

Input materials for these SRF`s differ considerably, and varies from the SRF production based on selected production wastes till different types of high calorific fractions.

Due to lacking uniform sampling methods for SRF the methods vary considerably. Partly national protocols or recommended procedures were used like RAL-GZ-724 or SFS 5875.

The analytical detection limits also differ considerably due to the different analytical techniques applied and the requirements of the users of SRF. They vary from 0.01 mg/kg d till 3.0 mg/kg ar.

However, in spite of these differences in the conditions of input materials (sampling, sample preparation and analytical methods) common properties in the distribution of Cd can be derived for various SRF.

Generally a right skewed distribution occurs for Cd. The skewed distribution is more significant with a growing amount of data. A reduced analytical detection limit turns into more significant skewed distributions (see figures 6 and 7).

Table 5 shows the statistical results for the presented SRF`s.

Table 4a: overview about boundary conditions of SRF- Cd data

Designation	Number of SRF represented	sampling method	sample preparation	analysing method	standard for analysing method	detection limit mg/kg d	number of analyses
AT 1	MSW	CEN292	5)	AAS	Onorm M6617,DIN EN ISO 5961	n.a.	97
AT 2	MSW+sludge	n.a.	n.a.	ICP-AES	Onorm EN ISO 11885	n.a.	81
AT 3	MSW+sludge	n.a.	n.a.	ICP-AES	Onorm EN ISO 11885	n.a.	85
AT 4	MSW	CEN292	6)	AAS	Onorm M6617,DIN EN ISO 5961	n.a.	50
B 1	select.com. waste	1)	1)	ICP	DIN 38406-E22-88	1	43
B 2	select.com. waste	1)	1)	ICP	DIN 38406-E22-88	1	45
B 3	filter cake	2)	2)	ICP/XRF	12)	3.0 13)	30
B 4	filter cake	2)	2)	ICP/XRF	12)	3.0 13)	44
B 5	filter cake	2)	2)	ICP/XRF	12)	3.0 13)	64
B 6	wood,sludge,act.carbon	2)	2)	ICP/XRF	12)	3.0 13)	704
B 7	resins,act.carbon,bleach,earth	2)	2)	ICP/XRF	12)	3.0 13)	11
B 8	polymers	2)	2)	ICP/XRF	12)	3.0 13)	42
FIN 1	source select.MSW	SFS 5875 3)	SFS 5875	GF-AAS	SFS 5502/5074(ENV 12506)	0.01	42
GE 1	select.com. waste	RAL-GZ 724 4)	RAL-GZ 724	AAS	DIN EN ISO 11885	0.2	86
GE 2	MSW	RAL-GZ 724 4)	RAL-GZ 724	AAS	DIN EN ISO 11885	0.2	51
GE 3	MSW	n.a.	n.a.	n.a.	n.a.	n.a.	70
GE 4	munic.sludge	n.a.	n.a.	AAS	DIN EN ISO 11885	n.a.	178
GE 5	munic.sludge	n.a.	n.a.	AAS	DIN EN ISO 11885	n.a.	178
GE 6	demol.wood	n.a.	n.a.	AAS	DIN EN ISO 11885	0,4	58
IT 1	MSW	UNI 9903-3 7)	UNI9903-3/12 7)	GF-AAS	ISO	0,05	61
IT3	MSW	UNI 9903-3 7)	UNI9903-3/12 7)	GF-AAS	ISO	0.05	13
N 1	demol.wood	SS 187113	n.a.	ICP-AES	n.a.	0.005	20
N 2	select.com.waste	SS 187113	n.a.	ICP-AES	n.a.	0.005	25
N 3	light ind./com.waste	8)	n.a.	ICP	NF EN ISO 11885	0.2-1 14)	28
NL 1	MSW	9)	9)	GF-AAS	NTA 8200	0.4	26
NL 2	MSW	9)	9)	GF-AAS	NTA 8200	0.4	26
NL 3	MSW	9)	9)	GF-AAS	NTA 8200	0.4	30
NL 4	MSW(WOF)	10)	10)	GF-AAS	NTA 8200	0.4	49
SE 1	waste wood	11)	11)	ICP-AES	EPA 200.7	0.01	28
SE 2	waste wood	11)	11)	ICP-AES	EPA 200.7	0.01	118
SE 3	select.com. waste	11)	11)	ICP-AES	EPA 200.7	0.01	17
SE 4	select.com. waste	11)	11)	ICP-AES	EPA 200.7	0.01	89
Total/Average							2489

n.a.: not available

1) Each shift a sample of about 1kg. Samples per day are mixed. Two analytic samples are produced by shredding: coarse 2 mm and fine 1mm (Used for metal analysis).

2) 6-8 increments/truck are mixed, about 2 kg/truck, daily samples mixed to 2 kg, daily samples mixed to week sample, size reduction to < 0,5 mm analysis (one sample corresponds to 300-500 ton).

3) 12 mm size material/sampling method from conveyor belt, 3 increments/day of a few liter, month sample reduced to 10 liter and send to laboratory

4) sampling per 500 tons 250 l (5 l every 10 tons), store 10 l, 10 l for analysis, reduce size < 1mm

5) > 100mm, size reduction < 30 mm, size reduction < 15 mm sample size 680 l, size reduction 1 mm sample size 10 l

6) < 50 mm size reduction, 20 mm sample size 200 l, size reduction < 1 mm sample size 10 l

7) 35 increments /sample, 2,4 kg/sample for 40 mm material, reduction to 1 mm for analysis

8) 1 increment/day (9 2 kg), 10 increments are mixed to a sample. Size reduction of the laboratory sample to < 1 mm.

9) sampling per day 250 l, size reduction < 40 mm, store 12.5 l and dry per week mix daily samples, store 15 l; per 4 weeks, mix week samples, reduce size < 1mm and send to laboratory

10) sampling per day 90 l, size reduction < 40 mm, store 10 l and dry; per week mix daily samples, store 10 l; per 4 weeks mix week samples, reduce size to < 1mm and send to laboratory

11) truck, wood chips: 1 sample/truck from 5 increments, 1 sample/month /Supplier composed of truck samples; truck/duff: 1 sample/month composed of 1 increment/truck;

ship: 4 lot samples/ship composed of increments taken every 20 minutes. The lot samples are mixed to a laboratory sample.

12) Round Robin with 54 laboratories

13) As received

14) laboratory of producer 17 assays, other laboratories d/ n.a.

Table 4b: overview about boundary conditions and Cd-distribution of SRF-data

Designation	number of analyses < detection limit	share of analyses with value <detection limit	number of values >...	share of analyses not charted	period of data	kind of distribution <i>calculation/optical evaluation</i>
AT 1	n.a.	n.a.	12 / 7.5	12%	4/2003	skewness right
AT 2	n.a.	n.a.	6 / 15	7%	10/2001,8/2003	skewness right
AT 3	n.a.	n.a.	4 / 15	5%	10/2001,8/2003	log normal
AT 4	n.a.	n.a.	0 / 7.5	0%	9/2003	log normal
B 1	40	93%	2 / 7.5	5%	1/2003-6/2003	skewness right
B 2	39	87%	3 / 7.5	7%	1/2003-6/2003	skewness right
B 3	30	100%	0/7.5	0%	2003-7/2004	not evaluable
B 4	44	100%	0/7.5	0%	2003-7/2004	not evaluable
B 5	64	100%	0/7.5	0%	2003-7/2004	not evaluable
B 6	704	100%	0/7.5	0%	2003-7/2004	not evaluable
B 7	11	100%	0/7.5	0%	2003-7/2004	not evaluable
B 8	42	100%	0/7.5	0%	2003-7/2004	not evaluable
FIN 1	0	0%	1 / 7.5	2%	3/1998-4/2003	log normal
GE 1	9	10%	1 / 7.5	1%	1/2002-9/2003	skewness right
GE 2	0	0%	0 / 7.5	0%	1/2002-9/2003	skewness right
GE 3	n.a.	n.a.	3 / 7.5	4%	n.a.	skewness right
GE 4	n.a.	n.a.	n.a.	6%	1/1998-12/1998	skewness right
GE 5	n.a.	n.a.	n.a.	6%	1/1998-12/1998	skewness right
GE 6	17	29%	n.a.	0%	6/1994-1/1998	skewness right
IT 1	0	0%	2 / 7.5	3%	2/2001-7/2003	skewness right
IT 3	0	0%	0 / 7.5	0%	1/2003-3/2004	(log normal)
N 1	0	0%	0 / 7.5	0%	2002-2004	(skewness right)
N 2	0	0%	0 / 7.5	0%	2002-2004	(skewness right)
N 3	n.a.	n.a.	0 / 7.5	0%	9/2003-5/2004	(skewness right)
NL 1	6	23%	3 / 7.5	11%	1/2002-3/2004	(skewness right)
NL 2	12	46%	2 / 7.5	8%	1/2002-3/2004	(skewness right)
NL 3	5	17%	1 / 7.5	3%	1998 - 2001	(log normal)
NL 4	4	8%	0 / 7.5	0%	9/2002-2/2004	skewness right
SE 1	0	0%	0 / 7.5	0%	7/2002-1/2004	(skewness right)
SE 2	0	0%	0 / 7.5	0%	7/2002-1/2004	skewness right
SE 3	0	0%	0 / 7.5	0%	7/2002-1/2004	(skewness right)
SE 4	0	0%	0 / 7.5	0%	7/2002-1/2004	skewness right
Total/Average	1045	42%		2%		

1): in brackets when the number of data is < 40

Table 5: overview about statistical outcome of the represented SRF's for Cd

Designation	median mg/kg d	arithmetic mean mg/kg d	80th perc. mg/kg d	90th perc. mg/kg d	maximum mg/kg d	standard deviation mg/kg d	rel. standard deviation mg/kg d	ratio 80./50. perc.	geometric mean mg/kg d
AT 1	3	3,80	4,8	8,42	13,9	2,60	68%	1,6	3,09
AT 2	6,00	6,85	11,2	13,2	26,3	5,96	87%	1,87	4,41
AT 3	5,30	6,12	8,32	10,68	20,7	4,03	66%	1,57	4,87
AT 4	0,7	1,07	1,6	2,54	4,9	1,03	96%	2,29	0,74
B 1	1,00	1,77	1,00	1,00	23,00	3,53	200%	1,00	1,17
B 2	1,00	1,73	1,00	2,00	12,00	2,40	138%	1,00	1,24
B 3	3,90	3,90	3,90	3,90	3,90	0,00	0%	1,00	3,90
B 4	5,60	5,60	5,60	5,60	5,60	0,00	0%	1,00	5,60
B 5	11,50	11,50	11,50	11,50	11,50	0,00	0%	1,00	11,50
B 6	4,10	4,10	4,10	4,10	4,10	0,00	0%	1,00	4,10
B 7	3,70	3,70	3,70	3,70	3,70	0,00	0%	1,00	3,70
B 8	3,00	3,00	3,00	3,00	3,00	0,00	0%	1,00	3,70
FIN 1	0,80	1,30	1,40	2,09	15,20	2,33	179%	1,75	0,71
GE 1	0,71	1,04	1,52	2,02	7,65	1,04	101%	2,14	0,74
GE 2	0,87	1,24	1,67	2,53	5,33	1,04	84%	1,92	0,97
GE 3	2,55	3,13	4,18	5,41	10,00	1,81	58%	1,64	2,73
GE 4	1,00	1,10	1,30	1,50	10,00	0,83	75%	1,30	0,95
GE 5	1,00	1,10	1,30	1,50	10,00	0,83	75%	1,30	0,95
GE 6	0,80	1,19	2,50	2,50	3,50	0,97	82%	3,13	0,83
IT 1	1,36	1,79	2,20	2,47	8,76	1,40	78%	1,62	1,51
IT 3	1,25	1,64	1,75	2,44	5,55	1,28	78%	1,40	1,38
N 1	0,55	0,81	0,74	1,06	5,70	1,20	147%	1,35	0,54
N 2	0,49	0,69	0,94	1,40	1,86	0,48	70%	1,91	0,55
N 3	0,63	0,68	1,00	1,03	1,55	0,35	52%	1,59	0,58
NL 1	2,20	5,56	6,18	15,05	36,80	8,89	160%	2,82	2,65
NL 2	0,80	2,83	1,28	2,38	42,90	8,37	296%	1,60	0,96
NL 3	1,10	1,53	1,80	3,00	8,10	1,67	109%	1,64	0,94
NL 4	1,60	1,80	2,60	3,20	6,60	1,20	67%	1,63	1,30
SE 1	0,62	1,25	1,76	2,33	5,63	1,34	108%	2,83	0,83
SE 2	0,42	0,55	0,64	1,04	2,45	0,44	79%	1,51	0,45
SE 3	0,86	1,12	1,27	1,57	2,91	0,56	50%	1,47	1,03
SE 4	0,53	0,75	0,90	1,29	5,97	0,85	113%	1,68	0,55
Total/Average	2,15	2,63	3,02	3,92	10,28	1,76	85%	1,61	2,16

100% of dl has been taken

B3-B8: dl of 3 mg/kg ar is put at this level to avoid interferences

Annex 6

OVERVIEW OF SECONDARY FUEL AND SRF QUALITIES

1. Sources for SRF

SRF is produced from non hazardous waste categories mentioned e.g. in the list of the BGS /13/. However, tyres, dried municipal sewage sludge and other non hazardous wastes are also used in the production of SFR.

2. Overview of SRF qualities

The tables based on information from several EU Member States give an overview of the composition of secondary fuels /2, 12, 14/. The comparison of the data is complicated by the different methods applied in sampling, sample preparation and analysis. Especially sampling and sample preparation may have a great influence on the outcome of the analysis. For practical reasons the number of analyses can tentatively be used as an indication for the reliability of the data, which means that data about SRF based on less than 10 analyses are presented within brackets. These data are not considered in the overview presented in tables 7-10.

Table 1 Overview of SRF qualities* (source MSW)

		SBS [®] 2		Dry residual		SBS [®] 1		TST		PP1	
Unit		m	80 p	m	max	m	80 p	m	80 p	m	80 p
NCV	MJ/kg ar	19.9	22.2	13.9	15.3	15.4	17.8	15.2	16.8	17.5	19.2
Moisture	%	15.4	20.5	31.8	39.0	24.4	31.5	13	19	30.0	31.3
Ash	% ar	10.1	13.0	7.4	9.9	12.6	14.9	-	-	7.3	9.2
Cl	% ar	0.61	0.88	0.25	0.75	0.34	0.44	0.49	0.81	0.23	0.43
Hg	mg/kg ar	0.17	0.19	0.09	0.26	0.19	0.37	0.31	0.46	0.17	0.17
Cd+Tl	mg/kg ar	1.70	3.92	0.70**	2.39**	0.78	1.3	1.44	1.83	2.0	4.6
Sum HM	mg/kg ar	272	737	(281)	(860)	283	853	595	1025	232	298
Hg	mg/MJ ar	0.008	0.009	0.006	0.018	0.012	0.024	0.020	0.030	0.010	0.010
Cd+Tl	mg/MJ ar	0.085	0.196	0.050	0.172	0.051	0.084	0.095	0.120	0.116	0.264
Sum HM	mg/MJ ar	13.7	37.0	20.2	61.9	18.4	55.4	39.1	67.4	13.3	17.0

		PP2		Tunka 2-15		PP mix		Italian SRF	
Unit		m	80 p	m	80 p	m	80 p	m	80 p
NCV	MJ/kg ar	14.4	15.0	9.8	11.4	14.3	15.9	17.6	18.6
Moisture	%	28.7	30.5	15.3	16.2	23.2	-	11.7	15.1
Ash	% ar	10.3	12.0	35.0	42.1	10.7	12.8	16.5	19.3
Cl	% ar	0.57	0.71	0.45	0.49	0.45	0.63	0.79	0.83
Hg	mg/kg ar	0.21	0.41	0.68	0.78	0.28	0.41	0.47	0.83
Cd+Tl	mg/kg ar	0.85	1.57	3.05	3.73	1.61	2.46	2.14	2.44
Sum HM	mg/kg ar	284	674	895	1043	216	325	457	581
Hg	mg/MJ ar	0.015	0.029	0.069	0.079	0.019	0.029	0.026	0.047
Cd+Tl	mg/MJ ar	0.059	0.109	0.311	0.380	0.112	0.172	0.121	0.138
Sum HM	mg/MJ ar	19.7	46.8	91.3	106	15.1	22.7	26.0	33.0

* The overview is a selection of SRF qualities. The median value of the NCV ar is used for the calculation of the median (m) and 80th percentile (80 p) values of the specific concentrations (mg/MJ). Data in brackets concern less than 10 analyses.

** No reliable result available for Tl. Sum Cd + Tl estimated by multiplying Cd figure by 1.3, which is a rather conservative approach according to the data showed in annex 9.

SBS[®] 1 and 2 are produced from automatically sorted high calorific fractions of MSW by RWE Umwelt. For the assays < detection limit 50% of this value has been taken.

Dry residual: produced by Tampere Regional SWM from source selected household waste, 80th percentile value is not available

TST: Trockenstabilat[®] produced by the Herhof process

PP1, PP1 and PPMix: produced from MSW (the paper/plastic fraction) by Essent Milieu

Tunka 2-15: produced from the wet organic fraction of MSW by Essent Milieu

Italian SRF: produced from dried MSW (Ecodeco, Pirelli and Herhof/Fusina)

Table 2 Overview of SRF qualities* (source selected commercial waste)

		<i>Fluff</i>		<i>RDF pellets</i>		<i>Wood chips</i>		<i>Wood/paper</i>	
	<i>Unit</i>	<i>m</i>	<i>80 p</i>	<i>m</i>	<i>80 p</i>	<i>m</i>	<i>80 p</i>	<i>m</i>	<i>max</i>
NCV	MJ/kg ar	13.6	18.6	18.1	18.7	13.0	14.0	16.9	17.8
Moisture	%	23.5	28.8	2.9	3.5	25.7	33.8	13.8	21.9
Ash	% ar	7.2	9.4	15.8	16.1	2.1	3.6	5.0	7.9
Cl	% ar	0.11	0.29	0.58	0.58	0.04	0.07	0.1	0.3
Hg	mg/kg ar	0.11	0.17	0.19	0.029	0.07	0.07	0.09	0.43
Cd+Tl	mg/kg ar	0.46	0.71	1.09	1.39	0.10	0.10	0.54**	2.18**
Sum HM	mg/kg ar	227	455	595	1763	178	429	(262)	(348)
Hg	mg/MJ ar	0.008	0.012	0.010	0.016	0.005	0.005	0.005	0.025
Cd+Tl	mg/MJ ar	0.034	0.052	0.060	0.077	0.008	0.008	0.032	0.129
Sum HM	mg/MJ ar	16.7	33.4	32.9	97.4	13.7	33	(15.5)	(20.6)

		<i>BPG®</i>		<i>Cement</i>		<i>Lime</i>		<i>Norwegian SRF</i>	
	<i>Unit</i>	<i>m</i>	<i>80 p</i>	<i>m</i>	<i>80 p</i>	<i>m</i>	<i>80 p</i>	<i>m</i>	<i>80 p</i>
NCV	MJ/kg ar	21.8	23.9	26.0	29.0	31.0	32.1	13.0	14.8
Moisture	%	9.9	15.3	6.9	15.6	1.6	3.3	23.5	-
Ash	% ar	8.9	10.7	11.0	13.0	3.0	9.5	-	-
Cl	% ar	0.39	0.58	0.6	1.0	0.4	0.9	0.22	0.31
Hg	mg/kg ar	0.09	0.12	<1.0	<1.0	<1.0	<2.0	0.38	0.69
Cd+Tl	mg/kg ar	0.98	2.17	<1.0	<1.0	<1.0	<1.0	0.63**	0.99**
Sum HM	mg/kg ar	141	305	324	576	190	325	-	-
Hg	mg/MJ ar	0.004	0.005	<0.036	<0.036	<0.032	<0.063	0.029	0.053
Cd+Tl	mg/MJ ar	0.045	0.099	<0.036	<0.036	<0.032	<0.032	0.048	0.076
Sum HM	mg/MJ ar	6.5	14.0	12.5	22.1	6.1	10.5	-	-

* The overview is a selection of SRF qualities. The median value of the NCV ar is used for the calculation of the median (m) and 80th percentile (80 p) values of the specific concentrations (mg/MJ). Data in brackets concern less than 10 analyses. 80th percentile figures were not available for wood/paper, the maximum value has been used.

** No reliable result available for Tl. Sum Cd + Tl estimated by multiplying Cd figure by 1.3
 Fluff: mixture of paper, plastics and wood from selected commercial waste used by Söderenergi
 RDF: pellets produced from selected commercial waste used by Söderenergi
 Wood: recycled wood chips used by Söderenergi
 Wood/paper: produced by Tampere Regional SWM from source selected commercial waste, mixed with wood
 BPG®: produced from source-separated wastes by RWE Umwelt. For the assays < detection limit 50% of this.
 Cement-pellets: produced by Indaver from source selected commercial waste with a maximum of 25% residue from the recycling of plastic/metal packaging waste material
 Lime-pellets: produced by Indaver from the same category of wastes as cement-pellets
 Norwegian SRF: produced from selected industrial and commercial wastes

Table 3 Overview of SRF qualities* produced for cement kilns

	Unit	SRF1		SRF2		SRF3		SRF4		SRF5		SRF6	
		m	80 p	m	80 p	m	80 p	m	80 p	m	80 p	m	80 p
NCV	MJ/kg ar	10	12	4	4.6	3.2	3.4	11.7	12.8	7.1	10.3	25.5	25.8
Moisture	%	23.3	32	46.9	48.5	73.9	75	27.2	34	19.8	23.4	0.5	0.9
Ash	% dry	50.8	68.9	52.6	57.4	35.2	38.4	14.9	18	42.2	42.5	<1	<1
Cl	% ar	0.29	0.44	0.07	0.14	0.32	0.4	0.3	0.44	0.77	0.82	1.7	2
Hg	mg/kg ar	<0.5	0.64	0.5	0.5	1.3	2.5	0.5	1.6	0.5	0.5	<0.5	<0.5
Cd+Tl**	mg/kg ar	<3	3	<3	3	<3	3	<3	3	<3	<3	<3	<3
Sum HM	mg/kg ar	1305	1562	280	466	223	260	1068	1554	463	618	180	270
Hg	mg/MJ ar	<0.05	0.064	0.125	0.125	0.406	0.781	0.042	0.137	0.070	0.070	<0.02	<0.02
Cd+Tl	mg/MJ ar	<0.3	0.30	<0.75	0.75	<0.93	0.94	0.26	0.26	<0.42	0.42	<0.12	<0.12
Sum HM	mg/MJ ar	130	156	70	116	69.7	81.2	91.3	133	65.2	87	7.0	10.6

* The overview is a selection of SRF qualities. The median value of the NCV ar is used for the calculation of the median (m) and 80th percentile (80 p) values of the specific concentrations (mg/MJar). Mn concentrations have not been determined.

SRF 1-6 are used by cement kilns as fuel and concerning the ash content as substitute for raw materials, which means that the ash composition should meet the requirements dealing with the quality of the clinker.

** The concentration of Cd and Tl is often below the detection limit. In those cases where both elements are below the detection limit only the detection limit of Cd is taken into account.

Sources for SRF 1-6 are:

SRF1: Mainly filter cake (dried and wet) from industrial and municipal sewage sludge and saw dust.

SRF2: Mainly wet filter cake from industrial sewage sludge mixed with saw dust.

SRF3: Mainly wet filter cake.

SRF4: Mainly waste wood, filter cake, aluminium hydroxide sludge, spent activated carbon.

SRF5: Mainly polymer resins, spent activated carbon, bleaching earth.

SRF6: Polymers.

Annex 7

HEAVY METALS IN SRF

1. Introduction

Solid fuels or raw materials used in the production of energy and cement clinker contain heavy metals. The usage of secondary fuels and materials could increase the dispersion of heavy metals in the environment through emission to the air and/or leaching from the product. Therefore special attention is taken to avoid unacceptable emissions to air during the combustion process or to water by leaching from the product.

In this annex the compositions of primary and secondary fuels and primary raw materials are presented. More specific the situation concerning Hg will be described. The limits for heavy metals set in section 5.2, table 19 are discussed in relation to the usage and the technology involved.

2. Overview of heavy metals concentration

Table 1 gives an overview of the concentration of the WID relevant heavy metals.

Table 1 Overview of heavy metal concentrations

		Raw materials				Solid fuels												
	Unit	Clay and Argillite /3/	Limestone, lime marl, chalk /3/	Fly ash /24/	Hard coal, Brown coal /3/	Hard coal (model) /10/		Brown coal (model) /10/		Sewage sludge /15/	Municipal Se-wage Sludge /16/	SBS [®] 1 Data 2002 - 2003		RDF		SRF 1		Tyres /25/
						Mean	High	Mean	High			Median	80 p	Median	80 p	Median	80 p	
NCV	MJ/kg d	-	-	-	7 – 38 /15/	27.8	27.8	22.2	24.2	9 – 12	n.a.	21.2	24.3	18.1	19.5	13.7	16.3	25
Moisture	%	n.a.	n.a.	-	3 – 60 /15/			52.7	54.4	65 – 75	77.5	24.4	31.5	2.9	3.5	23.3	32	2
Ash	% ar	n.a.	n.a.	-	3 – 17 /15/					40- 60	n.a.	12.6	14.9	15.8	16.1	39.0	52.8	15-20
Hg	Mg/kg d	0.02 – 0.15	< 0.01 – 0.13	0.007 – 0.61	0.1 – 3.3	0.2	1.2	0.05	0.9	0.2 – 4.5	< 1.2	0.25	0.45	0.2	0.3	0.65	0.83	0.17
Cd	Mg/kg d	0.02 – 0.3	0.04 – 0.7	< 0.10 – 7.3	< 0.1 – 10	0.3	10	0.01	0.35	4 – 6.5	< 1.7	0.84	1.72	1.1	1.4	6.52	14.3	8 (max.)
Tl	Mg/kg d	0.7 – 1.6	0.05 – 1.6	< 0.40 – 4.6	0.1 – 5.5	0.3	1.2	0.09	0.2	n.a.	n.a.	0.18	0.18	0.02	0.03	3.91	3.91	0.26
Sb	Mg/kg d	n.a.	< 1 – 3	< 1 – 11	0.4 – 2	2.5	9	0.24	2.4	2.4 – 8.5	n.a.	11.3	19.8	14.7	23.1	26.1	48.2	0.01
As	Mg/kg d	13 – 23	0.2 – 20	0.3 – 187	1 – 50	13.6	50	0.82	2.5	4 – 9.2	< 13	0.35	1.13	1.2	1.8	7.82	18.2	5-20
Pb	Mg/kg d	10 – 40	0.3 – 21	3.2 – 209	1.5 – 273	68	270	0.81	4	15 – 412	159	44.9	59.8	157	215	455	856	410
Cr	Mg/kg d	20 – 109	1.2 – 21	6.4 – 314	1.5 – 81	26.5	80	5.1	15	40 – 108.6	30	60.0	114	33.9	46.5	278	322	97-150
Co	Mg/kg d	10 – 20	0.5 – 5	2.1 -103	<1 – 40	16.7	40	3.5	15	2 – 13.4	n.a.	4.3	7.3	3.6	5.4	16.9	26.1	200
Cu	Mg/kg d	n.a.	3 – 12	4.1 – 391	1 – 100	33	60	1.2	4	30 – 434	363	91.3	552	266	1372	498	755	15
Mn	Mg/kg d	n.a.	< 250	-	82 – 250	125	315	116	260	210 – 1000	n.a.	54.9	71.6	117	125	n.d.	n.d.	n.d.
Ni	Mg/kg d	11 – 70	1.5 – 21	19-212	< 1 – 100	45	96	9.3	11	30 – 57	28	12.2	23.5	15.4	23.3	128	177	10-77
V	Mg/kg d	98 – 70	4 – 80	24 - 466	1 – 200	75	180	2	4	9 – 35.4	n.a.	4.15	4.69	3.3	3.8	45.6	61.3	1-5

Note: SBS[®]1, RDF pellets and SRF 1 represent the solid recovered fuels mentioned in annex 5. SBS[®]1 is produced from automatically sorted high calorific fractions of MSW, RDF pellets are produced from source selected commercial waste. SRF 1 is produced for the cement industry

3. Hg content of SRF

The sources for SRF and secondary fuels are MSW, sewage sludge, commercial and industrial process related waste. The average Hg content of MSW has decreased from 4 mg/kg (1990) to 2 mg/kg (1997) /17/. This result was to a great extent due to the reduction of Hg content in batteries. Therefore for example in Denmark the annual consumption of mercury changed from 18 t/year in 1982/83 to 3.3 t/year in 2001 /19/.

The reduction of Hg in commercial waste is indicated by the decreasing concentration in BPG[®], (SRF recovered fuel produced from source-selected commercial waste). See figure 1.

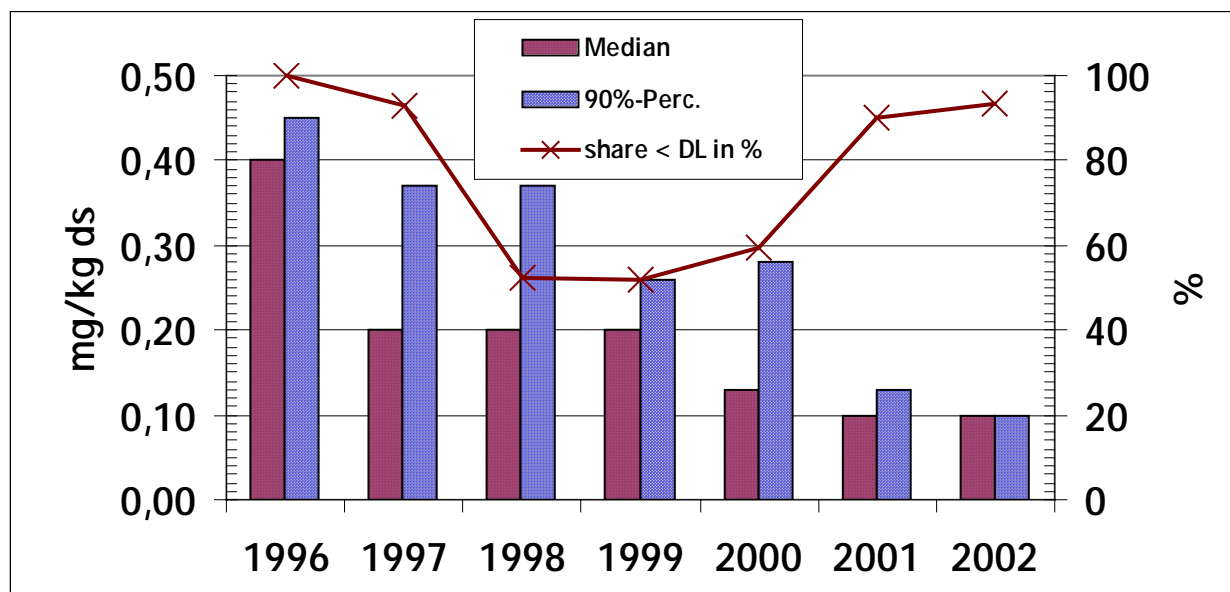


Figure 1 Change in mercury concentration in BPG[®] /20/.

Note: for assays < detection limit 50% of this value has been taken

Also in sewage sludge the mercury content is decreasing, see table 2.

Table 2 Hg content in sewage sludge, (Sweden) /18/

Year	Hg mg/kg d
1973	7
1983	5
1993	2.5
1998	1.8
2000	1.5

It may be concluded that the mercury content is decreasing in waste in those Member States that have implemented measures e.g. the source separation of batteries. Therefore the mercury content in secondary fuels will decrease subsequently.

4. Effects on heavy metal emission

4.1 Cement kiln /3/

Factors determining the emission behaviour of the individual heavy metals are the input situation, their behaviour in the kiln system as well as the collection efficiency of the dust collector. For the dry process, under the conditions of the clinker burning process, elements like As, Cr, Cu, Ni, Zn, Be and V introduced with the raw materials and fuels are more or less completely discharged from the kiln system with the clinker. In the same way Pb and Cd are more or less completely trapped in the clinker. In cyclone preheater kiln system, Pb and Cd output with the clinker is at equilibrium with a more or less pronounced Pb and Cd cycle between the kiln and preheater.

Tl and Hg are not captured in the clinker matrix. Tl compounds vaporize in the rotary kiln and, in cyclone preheater kilns, condense at temperatures of between 450 and 550 °C in the upper preheater section. The external Tl cycle is set up via the raw gas dust as a result of the process- inherent “overflow “of the internal cycle. The Tl emission level is determined by the concentration level of the external cycle and the collection efficiency of the dust collector. Hg forms gaseous components that condense on the raw material particles in the dust collector area. Condensation and hence, Hg removal increases with decreasing exhaust temperatures. Indications from measurements performed on cyclone preheater kiln systems are that more than 90 % of the Hg is present in particle- born form at exhaust gas temperatures below 130 °C. This means that the Hg compounds are virtually completely removed in the electrostatic precipitator of the kiln system.

In the Vito report /23/ the Hg emission was calculated for several scenarios concerning the co-incineration of non hazardous waste from Flanders. For the model calculations the Walloon cement kilns were assumed to be located in Flanders. The outcome shows that using SRF in cement kilns does not significantly influence the heavy metal emission situation in Flanders.

4.2 Coal fired power plants /22/

Heavy metals bound in most fossil fuels are liberated during combustion and may be released to the atmosphere on particles or as vapours. Metals are partitioned into several output streams, mainly combustion residues such as fly ashes but also flue gas, which enter downstream pollution control devices. Because of the large quantities of fuel consumed in energy generation, large amounts of potentially hazardous metals can be released into the environment. Most metal elements are associated with particulates. Volatile elements preferentially condense on the surface of smaller particles in the flue gas streams because of the greater surface area. Because volatile metal elements are enriched in the fine-grained particulate material carried downstream of the combustion chamber, the emission of these elements depends more on the efficiency of the gas cleaning system than upon the method of fuel conversion. Electrostatic precipitators and fabric filters are commonly used to remove particulate matter from flue gases generated by combustion plants burning solid or liquid fuels. These systems can operate with an overall efficiency of > 99.9%. However, the removal efficiency is generally lower in the smaller particle size range, i.e. the size range in which particles enriched with metal elements might be found. Fabric filters are better at controlling fine particulate matter and less sensitive to particulate loading and fly ash characteristics. The collection efficiency may be increased further by using flue gas conditioning with small amounts of additives added to the gas flow upstream of the filters. Wet scrubber FGD systems are an effective method for reducing emissions of certain metals. This is mostly because the flue gas temperature is reduced to about 50 – 60 °C by passing through the absorber, which allows many of the more volatile elements to condense from the vapour phase.

Secondary fuels such as sewage sludge and some other solid recovered fuel may contain some heavy metals in a higher concentration than conventional fuel, see also table 1 and table 20 on page 14. Some highly volatile metal components such as Cd, Hg and Tl will remain in the vapour phase or in an ultra fine fume. In considering secondary fuel, the Hg concentration is typically one of the most critical of all elements because of its volatility.

In reference /22/ some examples are described of plants where secondary fuels have been combusted. One example concerns a pulverised hard coal DBB using dried sewage sludge as secondary fuel (2.2 – 4,7 % dried sludge in the mass input). Atmospheric emissions of volatile heavy metals such as As and especially Hg might increase theoretically due to the co-combustion of sewage sludge. Practical data are shown in table 3.

Table 3 Emission values

	<i>Coal firing (mg/Nm³)</i>	<i>Co-combustion (mg/Nm³)</i>
Σ Cd, Tl	< 0.005	< 0.005
Hg	0.003 – 0.0012	0.0001 – 0.0013
Σ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Sn	< 0.075	< 0.075

The Hg concentration in the sewage sludge varied between 0.4 – 1.6 mg/kg d, no relevant concentrations of dioxins/furans were measured in any of the by products (ash, gypsum, waste water). The increase in heavy metal content in the by- products was insignificant and the quality of the by-products was virtually unchanged, thus the boiler ash, fly ash and gypsum can be recovered in the usual way.

5. Accumulation of heavy metals in products

The question of relevant accumulation of heavy metals in the product clinker including the behaviour when concrete is recycled has extensively investigated by e.g. the Association of German Cement plants (VDZ) /21/. Although the use of secondary fuels has virtually doubled in Germany from about 10% substitution in 1994 to about 19% in 1998 the ranges for heavy metal content have not changed. Environmental criteria for cement based products are mentioned in /26/. Results and main conclusions are:

There are significant differences in the generic leaching characteristics of different trace elements.

Confirming the results from previous studies, three different categories of elements can be identified with regard to their generic leaching behaviour:

- “Regular” metals, such as Pb, Cu, Cd, Ni, and Zn, showing a minimum leachability in the pH range 8 – 11.
- Elements occurring as “oxyanions” such as Cr, Mo, As, Sb, and V (i.e. chromate CrO₄, arsenate AsO₄) featuring a maximum leachability at neutral to slightly alkaline pH.
- Soluble salts showing no relationship with pH at all. Only a few constituents behave like this in cement based systems.

There is no systematic correlation between the total contents of trace elements in cement mortar and the leaching from mortar even under worst case conditions.

Table 4 shows the ratios between the maximum “available” trace element content (as obtained from the “availability” test on crushed mortar) and the “total” trace element contents (calculated for mortar), expressed as a percentage of the total. The ratio between the leached amount in tank leach test relative to the total content is given in a similar manner. The table demonstrates that there is no systematic trend or correlation in the ratios for the trace elements investigated. The total content of trace elements in cement may exceed the release of trace elements as observed in leaching tests by orders of magnitude and in the “availability” test by significant factors. Thus it is confirmed once again that the use of total trace element contents in cement as a regulatory tool has no sound scientific basis. Be, Hg, Tl and Sn are not considered in the table due to limited data or data below the limit of detection.

Table 4 Relationships between “total”, “available” trace element concentrations, leached quantity in batch test (L/S=10, pH 8 control), and in tank leach test for commercial and special cements (“availability” means leached amount under pH=4 at particle size < 125 µm, according to NEN 7341). All trace element concentrations are given as percentage of the total.

<i>Element</i>	<i>Availability Average</i>	<i>Batch (neutral pH) Average</i>	<i>Tank leach test (100y) Average</i>
As	12	0.5	0.001
Ba	64	11	0.02
Cd	54	1.8	0.004
Co	93	4.4	0.002
Cr	53	9.9	0.002
Cu	72	0.3	0.002
Mn	79	3.5	0.0000
Mo	34	8.8	0.003
Pb	30	0.8	0.0003
Sb	16	3.0	0.0008
Sn	3	0.3	0.003
Sr	99	22	
V	11	0.9	0.003
Zn	74	0.9	0.5

6. Limit values for Hg and Cd

The calculated possible maximum values for the different technologies and the limit values of the classes are associated in table 5.

Table 5 Technology and classes that may be accepted*

	<i>Cement</i>	<i>Hard Coal</i>		<i>Brown Coal</i>	<i>FBC</i>	<i>FBC (AC)</i>
<i>Boundary</i>		<i>DBB</i>	<i>WBB**</i>			
Hg median	1,2,3,4	1,2	1,2	1,2,3	1	1,2,3,4
80thperc.	1,2,3,4	1,2	(1)	1,2	-	1,2,3
Cd median	1,2,3,4	1,2,3	1	1,2	1,2	1,2,3,4,5
80thperc.	1,2,3	1,2	1	1	1,2	1,2,3,4,5

* Assuming median values for SRF at minimum 10 analyses. As boundary the median value and not the 80th percentile of a class should be taken, as the median values can be adequately compared with the limit values of the WID /9/. There is already a safety margin in the classification as has been argued in section 5.2.6. Moreover, all calculations have been based on 100% substitution, which will not be practice for coal fired power plants, which may have in the long run a maximum of 20% substitution. The 80th percentile value is solely shown for information.

** The data base for the TF of the WBB is rather limited and deducted in a rather conservative way. The experience with SRF and coal in this type of plant showed that emission limit values can be met. The fuel mix, the raw material and the specific TF together determine the actual emissions.

The SRF's with high ash content may be used in cement kilns and FBC (AC) having the highest possible maximum values. Both technologies may accept classes 1,2 and 3 at 80th percentile level of the SRF's or even class 4 at median level of the SRF's.

Cement kilns have a long experience in using wastes with a high ash content like filter cakes and wet or dried sludges. Especially those SRF's with a low NCV may be used in cement kilns. This type of recovery is an alternative for land spreading, especially for those wastes indicated as class 3 in /27/. The class 3 (classification of reference /27/) wastes may contain contaminants like pathogens, heavy metals and other potentially toxic elements, organic contaminants. Section 5 table 18 gives, based on the 50% rule, six examples of a class 4 SRF and four examples of a class 5 SRF. With respect to the use of classes it has to be considered that finally the fuel mix and the TF of the plant is determining. This means that class 4 and class 5 SRF may be used as well in cement kilns, which is existing practice.

The maximum values of heavy metals in SRF are set in accordance with the maximum values for blending of wastes. In The Netherlands the maximum for Hg is 10 mg/kg d /29/. In Belgium, France and Spain the maximum content for Hg is 5 or 10 mg/kg ar. The maximum for Cd (and for Tl) is in The Netherlands 100 mg/kg d for each element. The practical experience shows that there is a big difference between the maxima allowed and the average value, so that the emissions comply with the limit values of the WID. The maximum values for Hg, Cd (+Tl) in SRF will not interfere with actual practice. For the sum of the other heavy metals producers of SRF have developed their own standards. In France, the maximum content of heavy metals mainly used is 2500 mg/kg ar, in Belgium, Spain or other countries the limit is up to 7600 mg/kg ar. The minimum limit of the calorific value varies depending on the technical possibilities.

Annex 8

BOUNDARIES OF CLASSES

1. Basic assumptions:

1. Boundaries rely on a technical approach within the existing framework of environmental protection such as the Waste Incineration Directive and the restrictions on blending wastes practised in some Member States. This means no stricter values or new requirements for SRF.
2. Classes distinguish different qualities regarding the requirements of the users including their requirements related to environmental protection.
3. Requirements at stake concern economic value (NCV), technical constraints e.g. corrosion (CI) and environmental impact (Hg and Cd as indicator).
4. Maximum number of five classes as decided by the WG.
5. Value used to classify rely on 10 consecutive analyses for practical reasons. The number is a minimum for statistics and the data can be collected in a reasonable time.
6. The classes have a minimum or a maximum for the statistical value chosen. Open classes for NCV and CI are not in the interest of the users. They need to know the mean or median value in order to make their fuel mix, because of the requirements of a stable process.
7. The values for NCV have a normal distribution and the values for CI have usually a normal distribution. In these cases the mean value will be used in the classification system. Hg and Cd have a skewed distribution. In these cases the median values are used. For Hg and Cd also the 80 percentile value is used to ensure the environmental protection. The median Hg and Cd values may be used for the calculation of the load in the SRF. The 80th percentile values may be used to check whether the use of SRF comply with the environmental permits.

2. Boundaries decided by WG2 (February 2004)

Classification Property	Designation	Unit	Classes				
			1	2	3	4	5
Net calorific value (NCV)	Qp,net	MJ/kg ar mean	$25 < x \leq 45$	$20 < x \leq 25$	$15 < x \leq 20$	$10 < x \leq 15$	$3 < x \leq 10$
Classification Property			1	2	3	4	5
Chlorine	Cl	% ar median	$y \leq 0.1$	$0.1 < y \leq 0.5$	$0.5 < y \leq 1.0$	$1.0 < y \leq 1.5$	$1.5 < y \leq 6.0$
Classification Property			1	2	3	4	5
Mercury	Hg	mg/MJ ar median 80th perc.	<0.02 <0.04	<0.03 <0.06	<0.08 <0.16	<0.15 <0.30	<0.5 <1.0

3. Discussion

NCV

For many purposes the NCV should be between 10-15 MJ/kg. There are also clusters at about 5 and 22 MJ/kg. Using the classification proposed by the WG and taking the range of the mean value plus/minus 1,96x s less than 10% of the SRF's (reference are the SRF's mentioned in table 1) fits in the classes without overlap. Reduction of the standard deviation by taking sets of ten data does not improve the situation fundamentally (then the standard deviation is divided by the square root of the number of data, in this case 10). Therefore the approach should be in having only a minimum value for the classes, which is in line with e.g. the Italian standards (section 4). In line with

the approach followed with Hg and Cd relies the classification using sets of 10 data. The minimum NCV values of the SRF's are shown in table 1. Class 5 has a minimum at 3 MJ/kg ar. , which refers to experience in cement kilns using SRF with a high ash and high water content. Theoretically the basis is the calculation of the adiabatic flame temperature gives a graph that extrapolating data for common packaging materials to the requirement stated by the WID indicates 2,5 MJ/kg to be the lowest possible value (see also reference 28, prEN 13431:2003 annex B "Packaging –Requirements for packaging recoverable in the form of energy recovery, including specification of minimum inferior calorific value") A maximum is set at 45 MJ/kg ar.

Table 1 Overview of NCV MJ/kg ar

SRF designation	number of data	x					s	range x± 1,96s	
		median	mean	80th perc.	stdev	80/50th perc.		stdev./	min.
AT 1	10	12,4	12,4	12,8	0,60	1,03	0,19	12,1	12,8
AT 2	5	8,9	9,0	9,2	0,71	1,03	0,22	8,5	9,4
AT 3	3	10,2	9,6	10,5	1,42	1,03	0,45	8,8	10,5
AT 4	10	11,2	11,3	12,1	1,10	1,08	0,35	10,6	12,0
B 1	44	26,0	25,1	29,0	3,87	1,12	1,22	22,7	27,5
B 2	48	31,0	30,2	32,1	3,39	1,04	1,07	28,1	32,3
B 3	46	11,2	11,2	12,0	1,02	1,07	0,32	10,6	11,8
B 6	47	11,2	11,4	12,2	1,01	1,09	0,32	10,8	12,0
B 7	47	10,0	10,2	11,6	2,45	1,16	0,77	8,7	11,7
B 8	46	25,5	25,4	25,8	0,65	1,01	0,21	25,0	25,8
FIN 1	48	14,1	14,0	14,7	1,26	1,04	0,40	13,2	14,8
GE 1	249	21,7	21,9	23,4	1,89	1,08	0,60	20,7	23,1
GE 2	81	14,6	14,8	17,1	3,13	1,17	0,99	12,9	16,8
GE 3	68	12,8	12,7	14,6	2,10	1,14	0,66	11,4	14,0
GE 4	178		9,7						
GE 5	178		1,6						
GE 6	58		15,0						
IT 1	64	17,6	17,6	18,5	1,50	1,05	0,47	16,6	18,5
IT 3	13	16,1	16,6	18,6	2,13	1,15	0,67	15,3	17,9
N 1	19	13,1	13,1	13,8	1,46	1,05	0,46	12,2	14,0
N 2	30	16,0	15,9	17,9	2,45	1,12	0,77	14,4	17,4
N 3	31	13,0	12,4	14,8	3,50	1,14	1,10	10,2	14,5
NL 1	22	17,6	17,3	19,3	2,48	1,10	0,78	15,7	18,8
NL 2	22	14,2	14,1	14,8	0,95	1,04	0,30	13,5	14,7
NL 3	30	14,2	14,2	15,8	1,78	1,12	0,56	13,1	15,3
NL 4	52	8,5	8,6	9,9	1,86	1,17	0,59	7,4	9,7
SE 1	31	13,3	13,2	14,4	1,39	1,08	0,44	12,3	14,0
SE 2	124	13,3	13,1	14,2	1,58	1,06	0,50	12,1	14,0
SE 3	18	18,5	18,3	18,7	0,52	1,01	0,17	18,0	18,6
SE 4	90	13,2	13,0	14,1	1,35	1,06	0,43	12,2	13,9
Sum/average	2047	14,7	14,1	15,9	1,8	1,1	0,6	13,5	15,7

Cl

For many purposes the Cl content should be below 0,5 or between 0,5 and 1,0 %. Boilers can accept up to 0,3% without restrictions. As only two SRF's meet the requirements of <0,1 % d for class 1, the class boundary proposed is set at < 0,2 % d. The boundary for class 2 would be too close to class 1 and is set at 0,6% d. The WG decided on a maximum for class 5 of 3%, which seems a practical way to distinguish SRF from other wastes. Overlapping is also a problem for the classification of Cl. Therefore the solution is chosen having classes with a maximum value. In line with the approach followed for the other classification properties sets of 10 data are taken for the classification. The maximum Cl values of the SRF's are shown in table 2.

Table 2 Overview of Cl content in SRF % d

SRF designation	number of data	x				s		range $x \pm 1,96s$	
		median	mean	80th perc.	stdev	80/50th perc.	stdev./	min.	max.
AT 1	97	1,19	1,23	1,35	0,19	1,13	0,06	1,11	1,35
AT 2	25	0,68	0,81	0,92	0,44	1,36	0,14	0,54	1,09
AT 3	24	0,92	1,85	1,67	2,90	1,82	0,92	0,06	3,65
AT 4	50	0,61	0,62	0,69	0,10	1,14	0,03	0,56	0,68
B 1	126	0,60	0,75	1,00	0,65	1,67	0,21	0,34	1,15
B 2	145	0,40	0,63	0,90	0,70	2,25	0,22	0,20	1,07
B 3	46	0,42	0,43	0,49	0,10	1,17	0,03	0,37	0,49
B 5	335	1,37	1,42	1,75	0,39	1,28	0,12	1,18	1,66
B 6	47	0,34	0,38	0,49	0,14	1,44	0,04	0,29	0,47
B 7	47	0,41	0,44	0,61	0,27	1,49	0,09	0,27	0,61
B 8	46	1,75	1,75	2,00	0,26	1,14	0,08	1,59	1,91
FIN 1	42	0,39	0,40	0,50	0,21	1,30	0,07	0,27	0,53
GE 1	245	0,47	0,50	0,64	0,19	1,37	0,06	0,38	0,62
GE 2	89	0,50	0,53	0,64	0,17	1,28	0,05	0,42	0,64
GE 3	70	0,41	0,45	0,57	0,15	1,39	0,05	0,36	0,54
GE 6	55	0,10	0,18	0,20	0,23	2,00	0,07	0,04	0,32
IT 1	64	0,95	0,94	1,08	0,25	1,13	0,08	0,79	1,10
IT 3	13	0,91	0,89	0,99	0,16	1,09	0,05	0,79	0,99
N 1	20	0,05	0,05	0,08	0,03	1,60	0,01	0,03	0,06
N 2	30	0,22	0,26	0,35	0,13	1,59	0,04	0,18	0,34
N 3	31	0,29	0,34	0,40	0,21	1,38	0,07	0,21	0,47
NL 1	26	0,35	0,46	0,60	0,29	1,74	0,09	0,28	0,64
NL 2	26	0,80	0,77	1,00	0,29	1,25	0,09	0,59	0,94
NL 3	30	0,59	0,60	0,79	0,23	1,34	0,07	0,46	0,75
NL 4	49	0,55	0,56	0,62	0,11	1,13	0,04	0,49	0,63
SE 1	31	0,08	0,09	0,11	0,12	1,38	0,04	0,02	0,17
SE 2	124	0,04	0,04	0,05	0,02	1,25	0,01	0,03	0,05
SE 3	18	0,47	0,49	0,61	0,11	1,29	0,03	0,42	0,56
SE 4	90	0,18	0,26	0,30	0,33	1,68	0,10	0,06	0,46
Sum/average	2041	0,55	0,63	0,74	0,32	1,42	0,10	0,42	0,83

Hg

In the first draft of the classification document only the 80th percentile was used to classify the SRF's. A better option is using both 50th (median) and 80th percentile values. See also annex 5. From the characteristics of SRF's mentioned in annex 5 table 3 can be learned that the ratio 80/50th percentile varies between 1-4. The average being 1,58. For the classification 2 will be used as ratio. The maximum 80th percentile values of the classes were related to the maximum values calculated in section 2 (on 100% input of SRF) for different technologies See for a summary table 6. So four classes could be formed on this basis. A fifth class is proposed for those SRF's having a high content of e.g. sewage sludge and filter cakes. The maximum of this class is related to the lowest NCV and the maximum for blending Hg containing wastes. Assumed are a NCV of 3 MJ/kg ar and a Hg content of 5- 10mg/kg ar. The maximum has been rounded down at 1 mg/MJ.

The range in the median and 80th percentile values was tested with the random generator for several SRF's. The influence of the variation in median and 80th percentile on the classification is shown in table 18 of section 5.

The maximum possible Hg content has been calculated for different technologies in section 2. This calculation of the possible maximum for the specific concentration relies on a 100% input. In practice power plants will be limited in substitution of coal by SRF because of the Cl content and the influence on the ash quality, that often is used as filler in cement. We expect as a maximum for co-combustion in power plants 20 % substitution on a thermal basis. The substitution of regular fuel in cement kilns may vary between 50 and 100 %. In dedicated power plants (district heating plants) the input may be 100% SRF. Additionally we have to keep in mind that in practice plants prepare their own fuel mix made from e.g. hard coal, SRF, wood, biomass from e.g. the food and feed industry. Therefore it is difficult to prescribe the use of certain classes for specific technologies. Anyhow, the user remains responsible for the compliance with the limit values.

Cd

The approach for Cd is analogous to Hg in the design of the classes. A fifth class is proposed for those SRF's having a high content of e.g. sewage sludge and filter cakes. A maximum for blending Cd containing wastes is only known from the Netherlands being 100 mg/kg d which is 10 times higher than the Dutch maximum for Hg /29/. Then analogous to Hg the maximum of the fifth class will be 30 mg/MJ assuming a lowest NCV of 3 MJ/kg and a maximum for blending Cd containing wastes of $10 \cdot 10 = 100 \text{ mg/kg ar}$.

Annex 9

Thallium in SRF's

Thallium is used in electronic applications, chemical synthesis, and such minor uses as components for solders, low-melting alloys, low-temperature thermometers, and optical glasses. The concentration of Tl has been determined for the SRF's: NL 1-4, GE 1-2, SE 1-4. See table 1. The analytical results show usually values below or near the detection limit. The detection limits mentioned on the data sheets referring to the assays, differ from the overall detection limits reported by the producers. The overall level varies from 0.1-0.4 mg/kg d. The range in the dl of the assays varies from 0.02- 1.1 mg/kg d if the extreme values (the once-only figures) are omitted. In those cases with a very low detection level of 0.02- 0.03mg/kg d (SE1-4) the concentration varies between 0.02-0.04 mg/kg d (median) and 0.03-0.10 mg/kg d (80th percentile), with the highest values for SE 1 (imported wood). SE 3 and SE 4 that are derived from mixed commercial wastes have a concentration varying between 0.02 (median) and 0.03 (80th percentile). Summarizing it seems that the usual concentration of Tl in SRF's is lower than 0.1 mg/kg, most probably even lower than 0.04 mg/kg d. The contribution to the sum of Cd +Tl mg/MJ would be on the level of 0.002-0.004 mg/MJ which is negligible compared to Cd.

Table 1

data Tl mg/kg d

SRF	n	median	80th perc	max	dl datasheet	dl reported
NL1	26	0,35	1	2,1	0,35-1-1,1- 2,1	0,4
NL2	26	0,35	1	2,1	0,35-1-1,1- 2,1	0,4
NL3	30	1	1,1	70	0,2-0,4-0,5-0,7-1- 20-70	0,4
NL4	49	0,35	1,1	2	0,1-0,35-0,4-1,1-2-	0,4
GE1	71	0,35	0,35	0,4	0,35	0,35
GE2	43	0,35	0,35	0,35	0,35	0,35
SE1	27	0,04	0,1	0,15	0,02- 0,03 -0,1	0,1
SE2	118	0,02	0,03	0,1	0,02- 0,03	0,1
SE3	17	0,02	0,03	0,1	0,02-0,03- 0,1	0,1
SE4	90	0,02	0,03	0,04	0,02-0,03	0,1

bold figures are once-only