ANNEX 1

A.1.1 REGULATION (OR GUIDELINES) FOR GASEOUS EMISSIONS FROM MSW INCINERATION IN EUROPE

Component	Unit	EC* MSW	EC 94.67 Haz	A 1989	B 1993	CH 1991	D 1990	DK 1991	E*	I 1996	N	NL 1993	S 1993	UK 1992	F 1996	Component
Dust	mg/Nm³	30	10	15	10	10	10	30	100	10	10	5	30	30	30	Dust
HCl	mg/Nm³	50	10	10	10	20	10	50		20	100	10	50	30	50	HCl
HF	mg/Nm³	2	1	0,7	5	2	1	2		1	-	1	2	2	1	HF
SOx (as SO2)	mg/Nm³	300	50	50	50	50	50	300		100	300	40	200	300	300	SOx (as SO2)
CO	mg/Nm³	100	50	50	50	50	50	100	100	50	100	50	100	100	50	CO
NOx (as NO2)	mg/Nm³	-	-	100	400	80	200	-		200	-	70	400	350	400	NOx (as NO2)
TOC	mg/Nm³	20	10	20	-	20	10	20		10	-	10	-	20	10	TOC
Hg	mg/Nm³	0,2	0,05	0,01	50 µg	0,1	0,05	-		0,05	0,1	0,05	0,2	0,1	0,05	Hg
Cd	mg/Nm³	0,2	0,05	0,05	50 µg	0,1	-	-		-	-	0,05		0,1	0,05	Cd
PCDD/F	ngTEQ/Nm³	-	0,1	0,1	0,1	-	0,1	-		0,1	2	0,1	0,1	1	0,1	Cd PCDD/F
HPA	mg/Nm³									0,01						
Total métaux	mg/Nm³		0,5				0,5			0,5				6		

For MSW capacity > 30 t/h
* EC 84/429 and EC 89/369

* Regulation in force for existing plants in 1994 / European directive to be in force on 01.12.2000.

A1.2 -
DISTRIBUTION OF THE MSW ACCORDING TO THE DIFFERENT WAYS OF TREATMENT IN EUROPE

Country	Total MSW Amount* k tonnes / yr	Combustion * Wgt %	Landfill * Wgt %	Composting * Wgt %	Recycling * Wgt %	Amount* incinerated kt/yr OCDE 95	Amount** incinerated kt/y ISWA 96	Amount*** incinerated kt/yr Juniper 97
A	3841	17	40	18	25	653	407	510
B	4781	31	55	6	8	1482	-	2151
CH	2660	76	7	5	12	2021	2844	2722
D	25777	25	34	8	33	6444	9569	13121
DK	2788	56	21	11	12	1561	2593	2814
E	14296	5	83	12	0	715	672	1072
F	28000	37	55	7	1	10360	9542	10830
GR	3200	0,5	92.5	-	7	1	-	0
I	27000	5	95	-	-	1400	2100	3407
IRL	1550	-	92	-	8	0	-	0
L	218	58	4	4	34	126	-	150
N	2637	17	68	1	14	448	417	440
NL	8956	26	37	22	15	2234	2348	3600
P	3500	-	88	12	-	0	-	0
S	3900	41	40	3	16	1600	672	2094
SF	2100	2	62	3	33	50	-	50
UK	20000	12,5	82.5	-	5	2500	1713	2140
Europe	155200	20	51	6	10	31600	38735	45101
EC	149910	21	51,5	6,5	10	29130	35474	40193

* Source = OCDE (1995) - EUROSTAT (1993)
** Source ISWA (1996)
*** Source Juniper (1997)

A1.3 - INCINERATOR TECHNOLOGY - Main types of furnaces used for MSW incineration

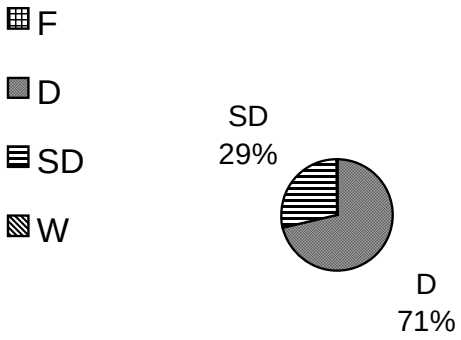
	Grate Systems						Kilns		Fluidized bed
Country	Rotating and moving grate	reciproca-ting grate	Roller gr.	stoker grate	travelling grate	other grates	Oscill.	Rotary	
AUSTRIA				2	4				
BELGIUM	4	7	1		12	12	3		
DENMARK	9		18		28	3	4	11	
FINLAND					2				
FRANCE	17	3	16	43	57	18	7	2	
GERMANY	43	49		15	22	1		2	
ITALY	1	9			27	1			1
LUXEMBOURG				3					
NETHERLANDS		17		12	15			3	
NORWAY		6			3			3	
SPAIN	2			2	5	1			3
SWEDEN			4	3	22				3
SWITZERLAND		19		10	12	2			
UK				5	2				
Total EC	76	85	39	85	196	36	14	18	7

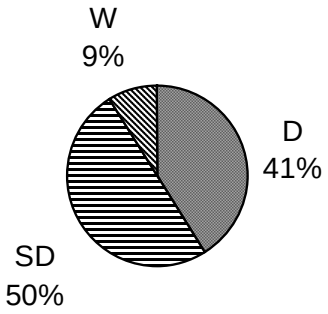
A1.4 - Number of Plants and capacities per countries

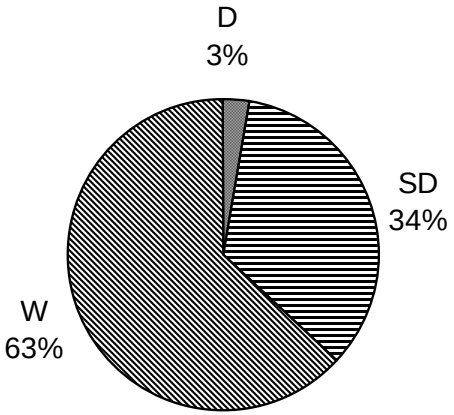
	JUNIPER SOURCES 1997 Plants > 30 kt/year		ISWA SOURCES 1996 Plants > 10 kT/year		OCDE 1995	
	Number of	Total capacity	Number of	Total capacity	Number of	Total capacity
COUNTRY	plants	KT/y	plants	KT/y	plants	KT/y
AUSTRIA	3	510	2	407	22	1630
BELGIUM	17	2151			18	
DENMARK	26	2814	34	2593	32	2400
FINLAND	1	50				
France	77	10830	95	9542	297	11408
GERMANY	43	13121	36	9569	138	
ITALY	32	3407	15	2100	204	1912
LUXEMBOURG	1	150			1	
NETHERLANDS	11	3600	6	2348	12	2700
NORWAY	5	440	5	417	12	
SPAIN	7	1072	6	672	20	625
SWEDEN	15	2094	21	1827	21	1700
SWITZERLAND	26	2722	28	2845	30	2488
UK	7	2140	12	1713	214	
TOTAL EC	240	41139				

BELGIUM

	1960 - 69				1970 - 79				1980 - 89				1990 - 99			
APC Tr system	F	D	SD	W	F	D	SD	W	F	D	SD	W	F	D	SD	W
Number of plants						2	1			4	4	1		1	8	8
Capacity kT/yr						122	50			357	430	75		60	740	1360
Total capacity kT/yr						172				862				2160		
APC process distribution						71%	29%			41%	50%	9%		3%	34%	63%

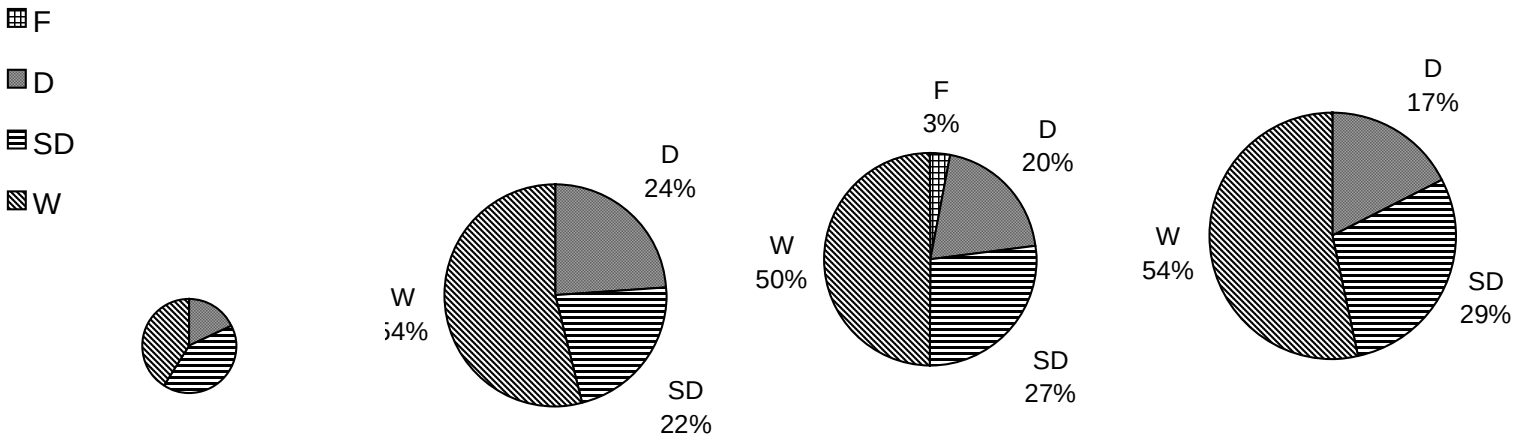






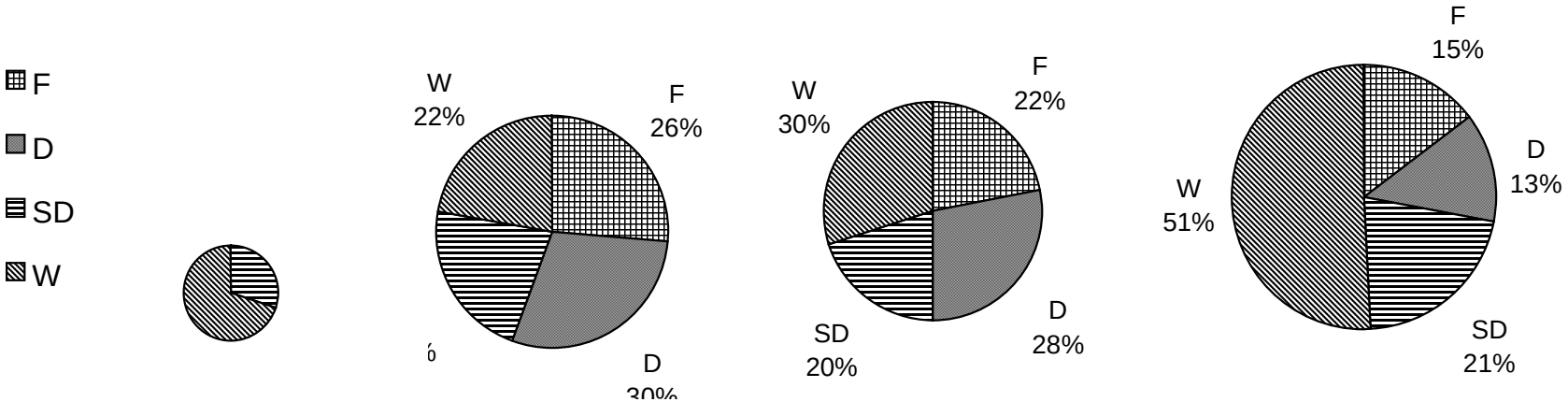
DENMARK

	1960 - 69				1970 - 79				1980 - 89				1990 - 99			
APC Tr system	F	D	SD	W	F	D	SD	W	F	D	SD	W	F	D	SD	W
Number of plants		1	1	3		6	2	6	1	8	6	9		8	7	11
Capacity kT/yr		75	170	173		420	370	928	73	482	660	1203		480	800	1470
Total capacity kT/yr	418				1718				2418				2820			
APC process distribution		18%	41%	41%		24%	22%	54%	3%	20%	27%	50%		17%	28%	52%



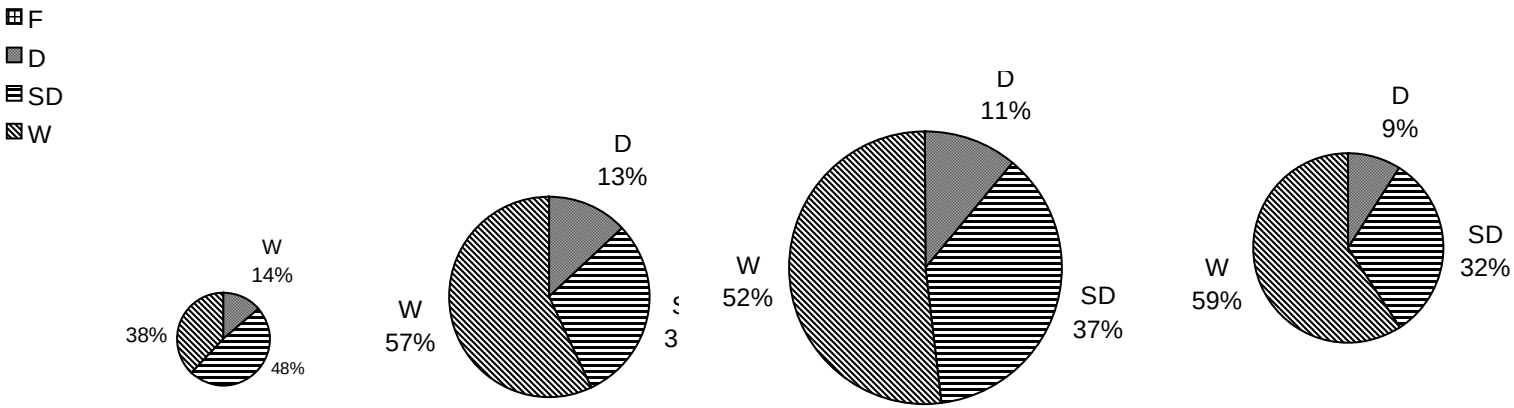
FRANCE

	1960 - 69				1970 - 79				1980 - 89				1990 - 99			
APC Tr system	F	D	SD	W	F	D	SD	W	F	D	SD	W	F	D	SD	W
Number of plants			1	1	10	10	6	6	13	16	9	13	14	16	18	29
Capacity kT/yr			85	200	1129	1232	953	952	1334	1716	1212	1835	1600	1440	2280	5500
Total capacity kT/yr	285				4266				6097				10820			
APC process distribution			30%	70%	26%	29%	22%	22%	22%	28%	20%	30%	15%	13%	21%	51%



GERMANY

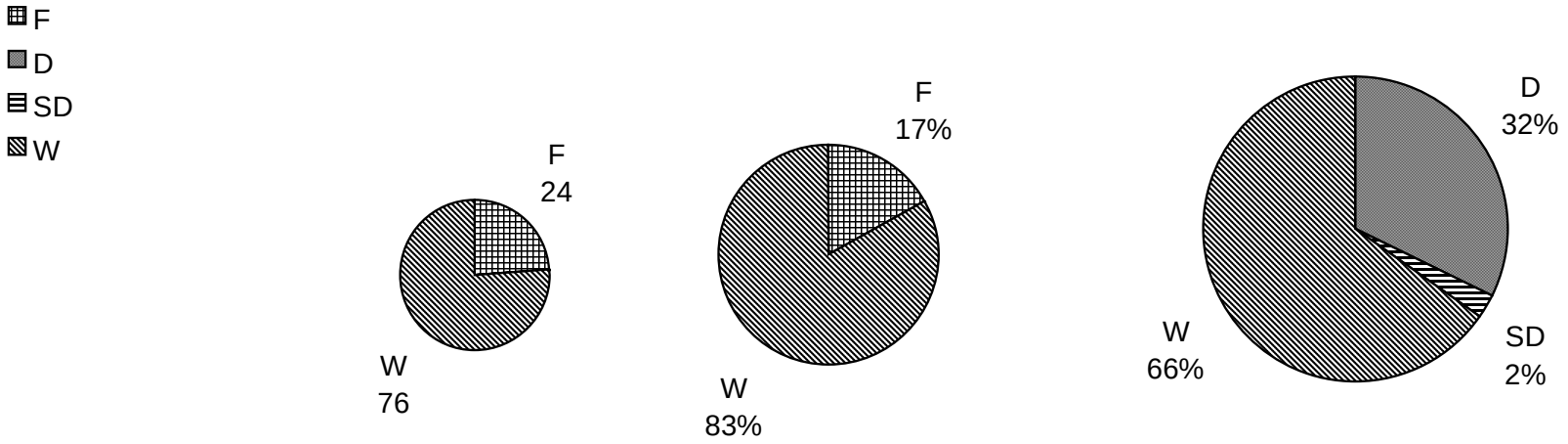
	1960 - 69				1970 - 79				1980 - 89				1990 - 98				1999*			
APC Tr system	F	D	SD	W	F	D	SD	W	F	D	SD	W	F	D	SD	W	F	D	SD	W
Number of plants		1	7	6		3	8	16		4	11	19		5	13	25			16	42
Capacity kT/yr		680	2275	1805		985	2441	4360		1159	3861	5485		1200	4100	7700				
Total capacity kT/yr	4760				7586				10505				13100							
APC process distribution		14%	48%	38%		13%	30%	57%		11%	37%	52%		9%	31%	59%			28%	62%



* Umweltbundesamt source [Joh99]

ITALY

	1960 - 69				1970 - 79				1980 - 89				1990 - 99			
APC Tr system	F	D	SD	W	F	D	SD	W	F	D	SD	W	F	D	SD	W
Number of plants				1	2			4	2			7		13	1	18
Capacity kT/yr				50	170			545	170			839		1100	80	2220
Total capacity kT/yr	50				715				1009				3400			
APC process distribution				100%	24%			76%	17%			83%		32%	2%	65%



NETHERLANDS

	1960 - 69				1970 - 79				1980 - 89				1990 - 99			
APC Tr system	F	D	SD	W	F	D	SD	W	F	D	SD	W	F	D	SD	W
Number of plants				1				5				6			1	10
Capacity kT/yr				380				2540				2860			80	5200
Total capacity kT/yr	380				2540				2860				5300			
APC process distribution				100%				100%				100%			2%	98%

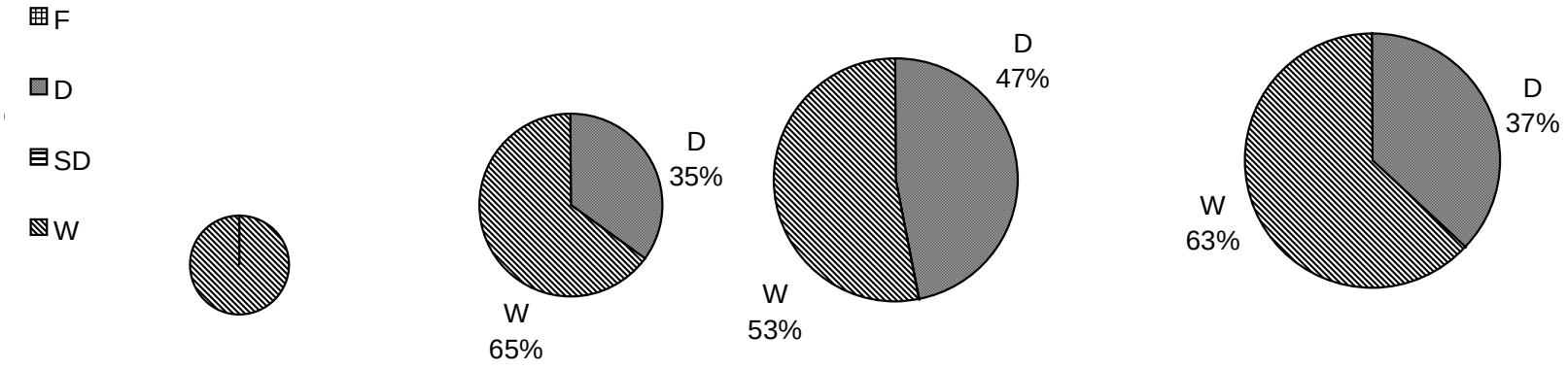
SPAIN

	1960 - 69				1970 - 79				1980 - 89				1990 - 99			
APC Tr system	F	D	SD	W	F	D	SD	W	F	D	SD	W	F	D	SD	W
Number of plants					1				3				4		2	
Capacity kT/yr					380				480				560		500	
Total capacity kT/yr					380				480				1100			
APC process distribution					100%				100%				52%		48%	

SWEDEN

	1960 - 69				1970 - 79				1980 - 89				1990 - 99			
APC Tr system	F	D	SD	W	F	D	SD	W	F	D	SD	W	F	D	SD	W
Number of plants				1		2		4		6		8		6		9*
Capacity kT/yr				250		370		687		778		866		778		1310*
Total capacity kT/yr	250				1057				1644				2094			
APC process distribution				100%		35%		65%		47%		53%		37%		63%

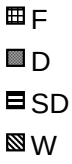
* assumed the Göteborg APC to wet

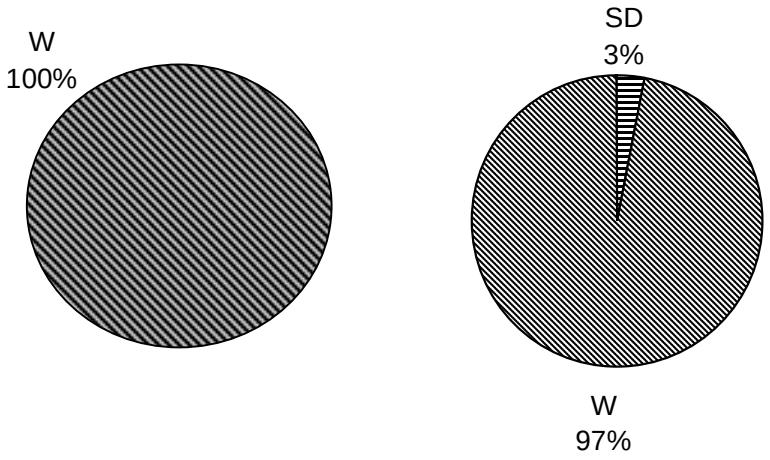


SWITZERLAND

	1960 - 69				1970 - 79				1980 - 89				1990 - 99				
APC Tr system	F	D	SD	W	F	D	SD	W	F	D	SD	W	F	D	SD	W	
Number of plants				5				17				18			1	23	
Capacity kT/yr				583				1729				1969			85	2640	*
Total capacity kT/yr	583				1729				1969				2720				
APC process distribution				100%				100%				100%			3%	97%	*

* based incinerator built in 1943 - rewamped in 98.





UNITED KINGDOM

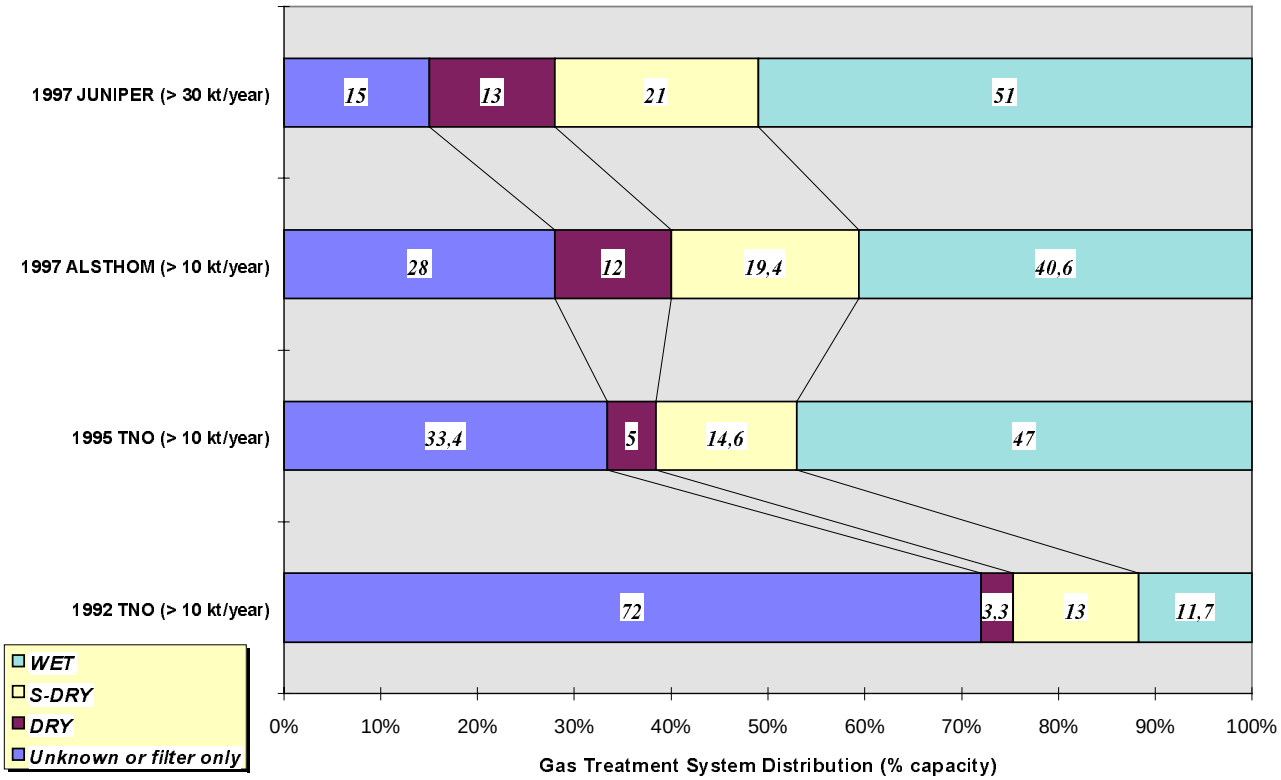
	1960 - 69				1970 - 79				1980 - 89				1990 - 99			
APC Tr system	F	D	SD	W	F	D	SD	W	F	D	SD	W	F	D	SD	W
Number of plants					24	4			24	4				4	3	
Capacity kT/yr					?	1140			?	1140				1140	1000	
Total capacity kT/yr													1996 : 2140*			
APC process distribution						100%				100%				53%	47%	

* 24 Incinerators have been shut down in 1996 for compliance with 1989 EC directive

Annex A1.6- COMPARISON OF THE DIFFERENT DATA BASE USED FOR THE INCINERATION FACILITIES REVIEW -

Application to the situation in France

Sources	Type	Number of plants	Capacity kt/year	A P C distribution				
				Unknown or filter only	DRY	S-DRY	WET	
TNO 1992	>10 kt	137	10310	114	6	12	5	*Number*
				7430	340	1340	1170	*kt/year*
				65	56	111	234	*kt/y/plant*
				72	3.3	13	11.7	*% capacity*
TNO 1995	>10 kt	95	8078	51	10	12	22	*Number*
				2681	403	1177	3816	*kt/year*
				52	40.3	98	177	*kt/y/plant*
				33.4	5	14.6	47	*% capacity*
ADEME 1989	No capacity	314	9000					
1993		308	10310					
1995	limitation	275	11282					
1996		277	11290					
2002		249						
Juniper 1997	>30 kt	77	10830	14	16	18	29	*Number*
				1621	1439	2277	5493	*kt/year*
				116	90	126	190	*kt/y/plant*
				15	13	21	51	*% capacity*
France (Alsthom) 1997	>10 kt	126	11628	60	22	19	25	*Number*
				3237	1412	2252	4725	*kt/year*
				54	64	118	189	*kt/y/plant*
				27.8	12	19.4	40.6	*% capacity*



Distribution of Incineration Capacities as a function of GTS Process in France

ANNEX 2

A2.1 - PVC COMPOSITION AS A FUNCTION OF ITS APPLICATIONS

Type of application	PVC type r	p	Filler, Impact modifier	Stabilizer	Lubricant int.	Lubricant ext.	Plasticiser	Other	Composition wgt % PVC	Filter	Stabilizer	Lubricant	Plasticiser	Other
Pipe and Tubing	x		CaCO3	Thiotin complex glycerol ester	monooleate	ester wax	-	-	93	3	2	1-3		
clear tubing for medical use		x		CaZn	glycerol ester	-	DOP + high mol. weight polyester		65	-	1-1.3	0-4	31	
Extruded profiles (building)	x		CaCO3 + ABS	tribasic Pb sulfate dibasic Pb "	fatty acid ester	Ca stéarate	-	-	82	5-16	6	2		
Extruded profiles flexibles (building)		x		Ba/Cd soap decyl-diphenyl-phosphIte	-	stearic acid -	DOP -	-	67		1	2.2	32	
Bottles for mineral water	x		MBS	Zn-octoate Ca-stearate organic phosphites epoxidised soja oil	fatty acid esters	-	-	processing aid : acrylic type	87	9-11	11.2	0.9-1.3		0.5-1
Bottles for general purposes	x		MBS	liquid thiotin	-	-	-	processing aid : acrylic type	88	9-11	1.3	0.9-1.3		0.9-1.6
Cable covering (general purpose)		x	whiting	basic Pb carbonate	-	basic Pb sterate	-	-	44	17	2		37	
H.T. cable compound		x	-	dibasic Pb phtalate	-	dibasic Pb phtalate	tri lissevol 79 trimetillate	flame retardant antimony trioxide	83		6	0.8	6	5
Flooring		x	Chrysotile / withing	Ca/Zn complex epoxydised soja oil		stearic acid	DOP	pigment :TiO2	25	65	2.3	0.2-0.5	3.8	2-4
Standart packaging rigid	x		di.n.octyl-tin	fatty alcohol	fatty acid ester	-	-	-	98		1.2-1.5	0.2-0.2		
Rigid food packaging	x		di.n.octyl-tin	glycerol ester	-	-	-	processing aid : acrylic polymer	97		1-1.5	1-1.6		0.8-2
Film for packaging		x	-	Ba/Cd liquid epoxydised soja oil	-	stearic acid	DCP tri-arylphosphate	UV absorber : Tinuwin	60		1.0-.1.2	0.1-0.3	39	0.1-0.2

* r = rigid* p = plasticized

Source W.V. Titow PVC Techno. 4th Edition

A2.2 PVC MATERIALS IN EC - Present status and trends

Plastics processors consumption by resin[1]
Western Europe (1995, 2001, 2006)

	Consumption		
	1995	2001	2006
LDPE	5 318	5 290	6 900
HDPE	3 503	4 455	5 200
PP	3 767	6 025	8 500
PVC	4 800	5 500	5 880
PS/EPS	2 525	2 910	3 120
PET	950	1 740	2 750
PU foams	1 280	1 440	1 500
Others	2 755	2 990	3 050
Total	24 909	31 350	36 900

Sources: SOFRES Conseil and petrochemicals companies
Unit: x 1000 tonnes
(1) Virgin + recycled resins

Post user plastic waste by resin
Western Europe (1995, 2001, 2006)

Polypropylene and PET waste streams are expected to increase very fast, for all types of application (building, car parts and packaging for PP, packaging for PET).

	Post user plastic waste			
	1995	2001	2006	% increase 1995-2006 (%)
LDPE	4 255	5 250	5 950	+ 40%
HDPE	2 553	3 300	3 890	+ 52%
PP	2 778	4 555	6 500	+ 133%
PVC	1 814	2 170	2 400	+ 32%
PS/EPS	1 574	1 830	1 980	+ 26%
PET	851	1 475	2 200	+ 158%
PU	562	630	650	+ 16%
Others	1 669	1 990	2 180	+ 31%
Total	16 056	21 200	27 750	+ 73%

Unit: x 1 000 tonnes, except specifically indicated.

A2.3 AMOUNT AND COMPOSITION OF MSW IN EUROPE

Country	Amount of MSW OCDE 1995		Putrescibles /fines	Paper	Plastic	Glass	Metals	Miscell (textiles incl.)
	k tonnes / yr	kg/capita	Wgt %	Wgt %	Wgt %	Wgt %	Wgt %	Wgt %
A	3841	310	50	22	7	9	5	8
B	4781	470	37	16	7	7	4	29
CH	2660	250	38	29	15	3	3	12
D	25777	320	44	24	7	9	6	10
DK	2788	530	36	20	5	4	2	35
E	14296	370	44	21	11	7	4	13
F	28000	470	29*	25*	11*	13*	4*	18*
GR	3200	310	49	20	9	5	5	13
I	27000	470	40	22	7	8	3	20
IRL	1550	430	29	33	9	6	3	20
L	218	530	44	19	8	7	3	20
N	2637	620	18	31	6	4	5	36
NL	8956	580	38	26	6	6	3	21
P	3500	350	35	23	12	5	3	23
S	3900	440	44	30	7	8	2	9
SF	2100	410	32	26	6	6	3	29
UK	20000	340	19	37	10	9	7	18
Europe	155204		35,9	25,3	8,7	8,6	4,4	17,3
EC	149907		37,1	26,2	9	8,9	4,5	17,9

Source = OCDE (1995) - EUROSTAT (1993)
* from ADEME Waste characterization campaign of 1993 (published in 1996).

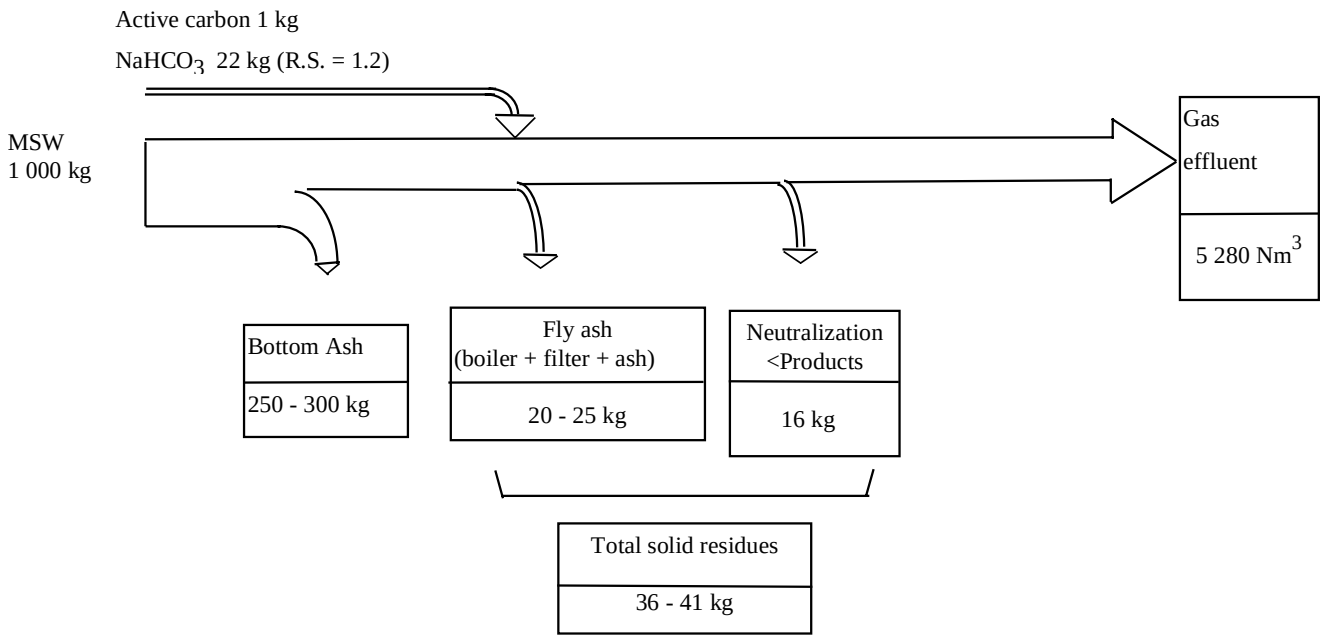
A2.4 - COMPOSITION AND WEIGHT OF THE PLASTICS TO BE INCINERATED WITH MSW IN EC

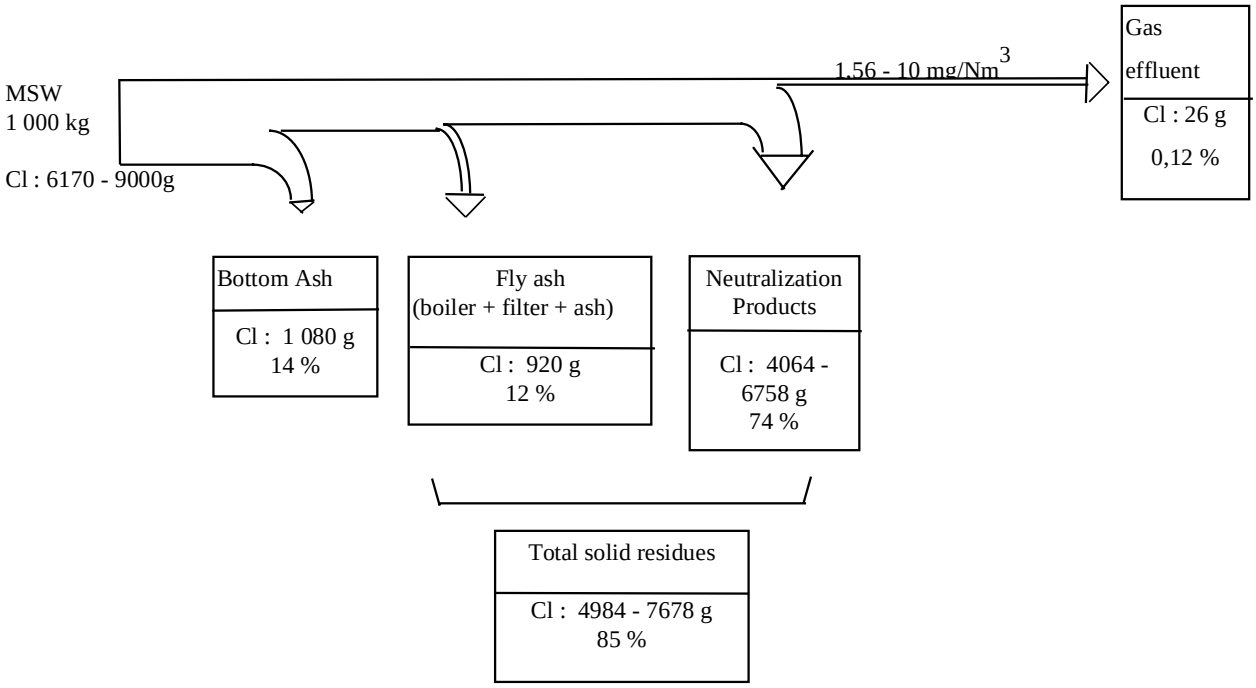
Country	MUNICIPAL WASTE				INCINERATED PLASTICS			INCINERATED PVC	
	MSW TOTAL INCINERATION				*	*	***		
	MSW kt/yr OCDE* (1)	Combustion wgt % OCDE* (2)	Incinerated MSW kt/yr according to OCDE* (3)	Incinerated MSW kt/yr according to Juniper** (up-dated) (4)	% in MW incin. (5)	kt/yr incinerated (5) * (3) = (6)	% PVC in the plastic fraction (7)	kt/yr incinerated (6) * (7) = (8)	% wgt in incinerated MW (8) / (3)
A	3841	17	653	510	7	45,7	9	4,1	0,63
B	4781	31	1482	2151	7	104	10	10,4	0,7
CH	2660	76	2021	2722	15	303,1	9	27,3	1,35
D	25777	25	6444	13121	7	451,	10	45,1	0,7
DK	2788	56	1561	2814	5	78	12	9,4	0,6
E	14296	5	715	1072	11	78,6	12	9,4	1,32
F	28000	37	10360	10830	10 [2]	1083 [2]	16 [2]	173 [2]	1,6 [2]
GR	3200	0,5	1	0	9	0,1	-		0
I	27000	5	1400	3407	7	98	8	7,8	0,56
IRL	1550	-	0	0	9	0	-		
L	218	58	126	150	8	10	10	1	0,8
N	2637	17	448	440	6	26,9	8	2,1	0,48
NL	8956	26	2234	3600	6	134	7	9,3	0,42
P	3500	-	0	0	12	0		0	
S	3900	41	1600	2094	7	112		0	0
SF	2100	2	50	50	6	3		0	0
UK	20000	12,5	2500	2140	10	250	10	25	1
Europe	155200	20	31600	45101	8	2834	10	283	0,63 – 0,7
EC	149910	21	29130	40193					

* According to OCDE (1995)
** According to Juniper (1997)
*** According to ISWA (1996)
[2] from ADEME (1993)

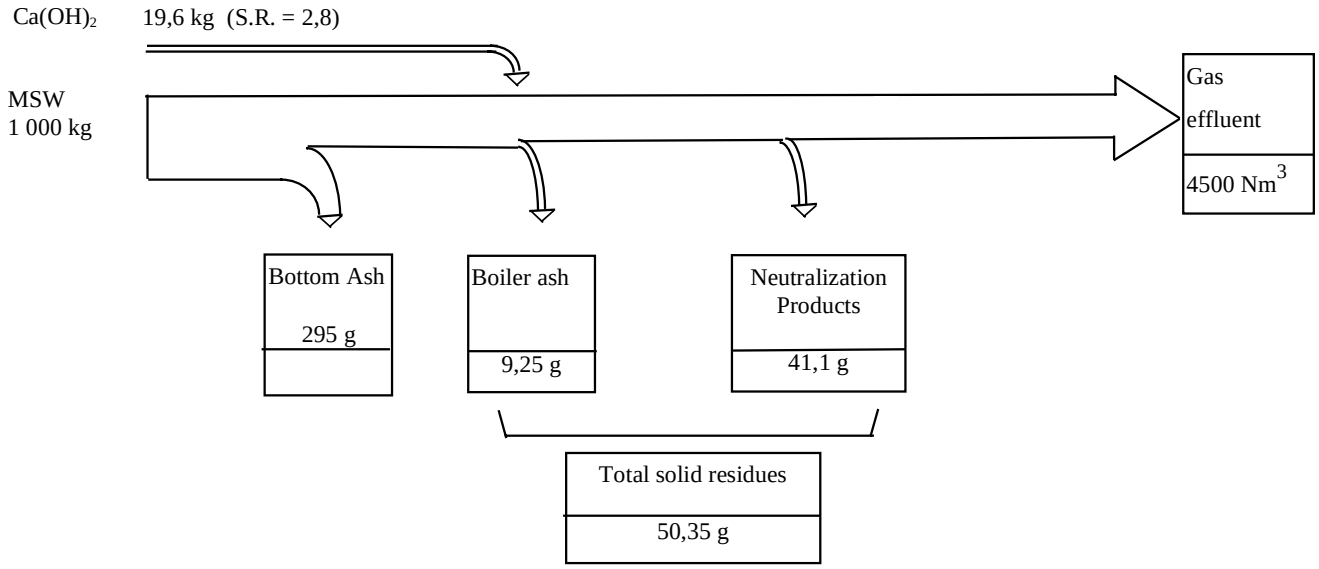
ANNEX 3

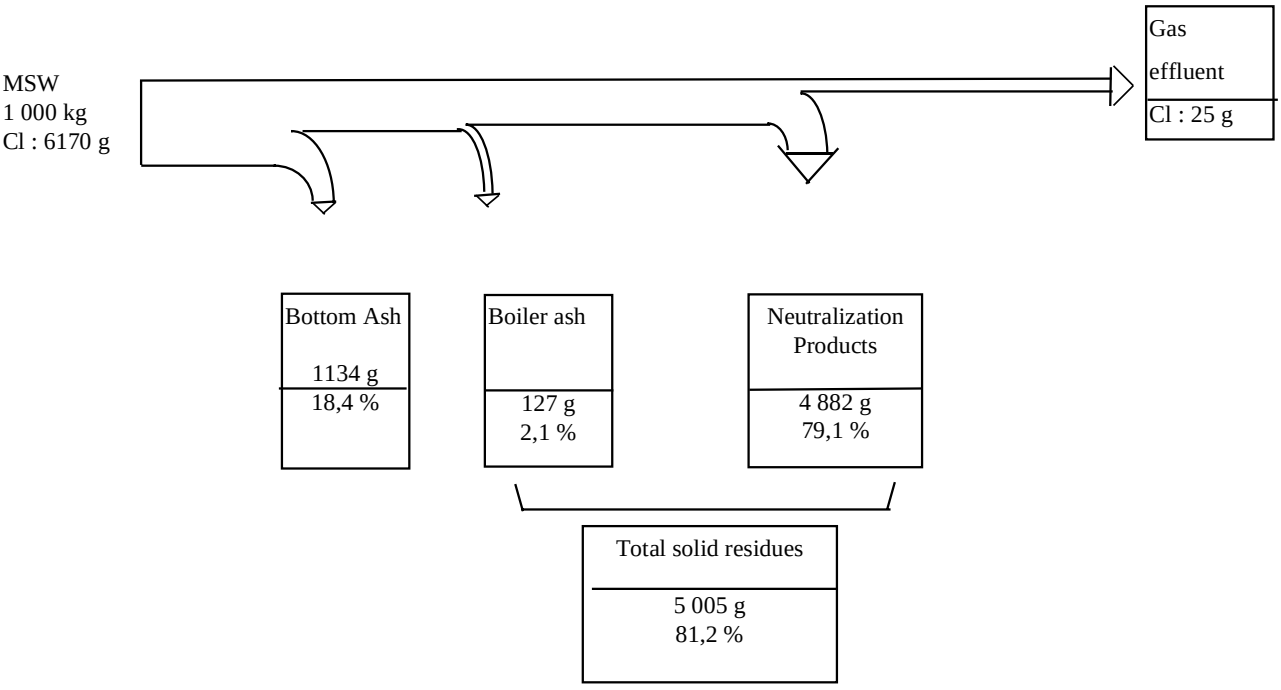
A3.1 Materials and Chlorine Distribution in Incineration - Dry Process with $NaHCO_3$- Reggio Emilia Experimental Results - 1996



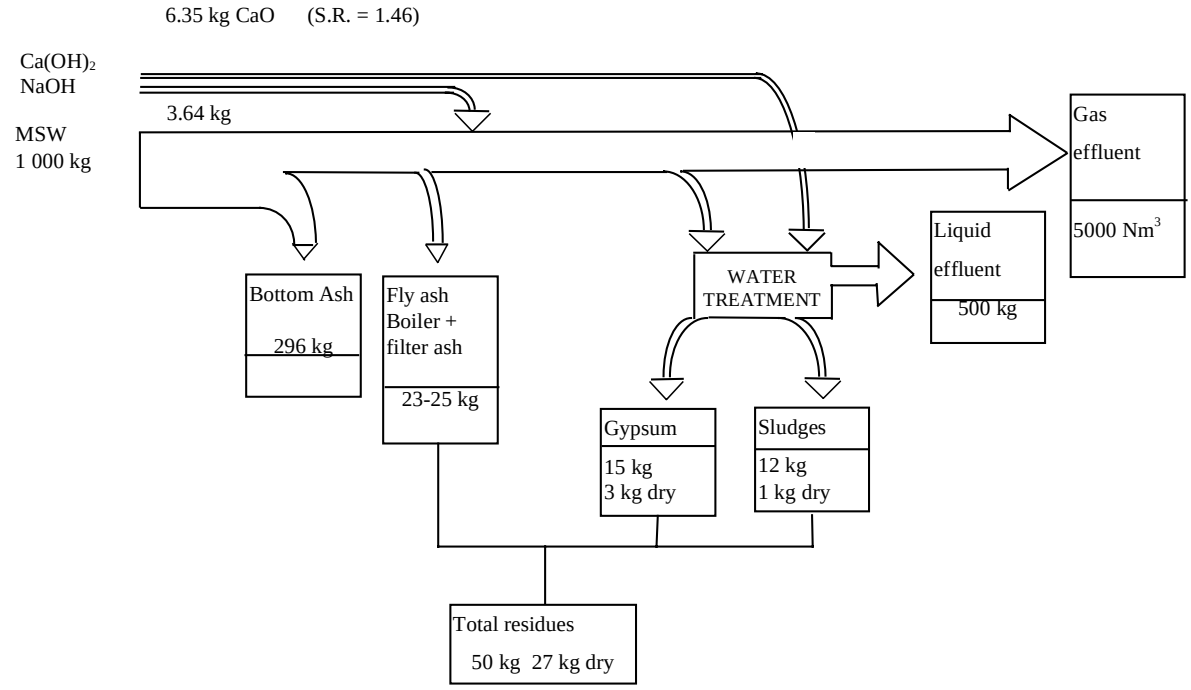


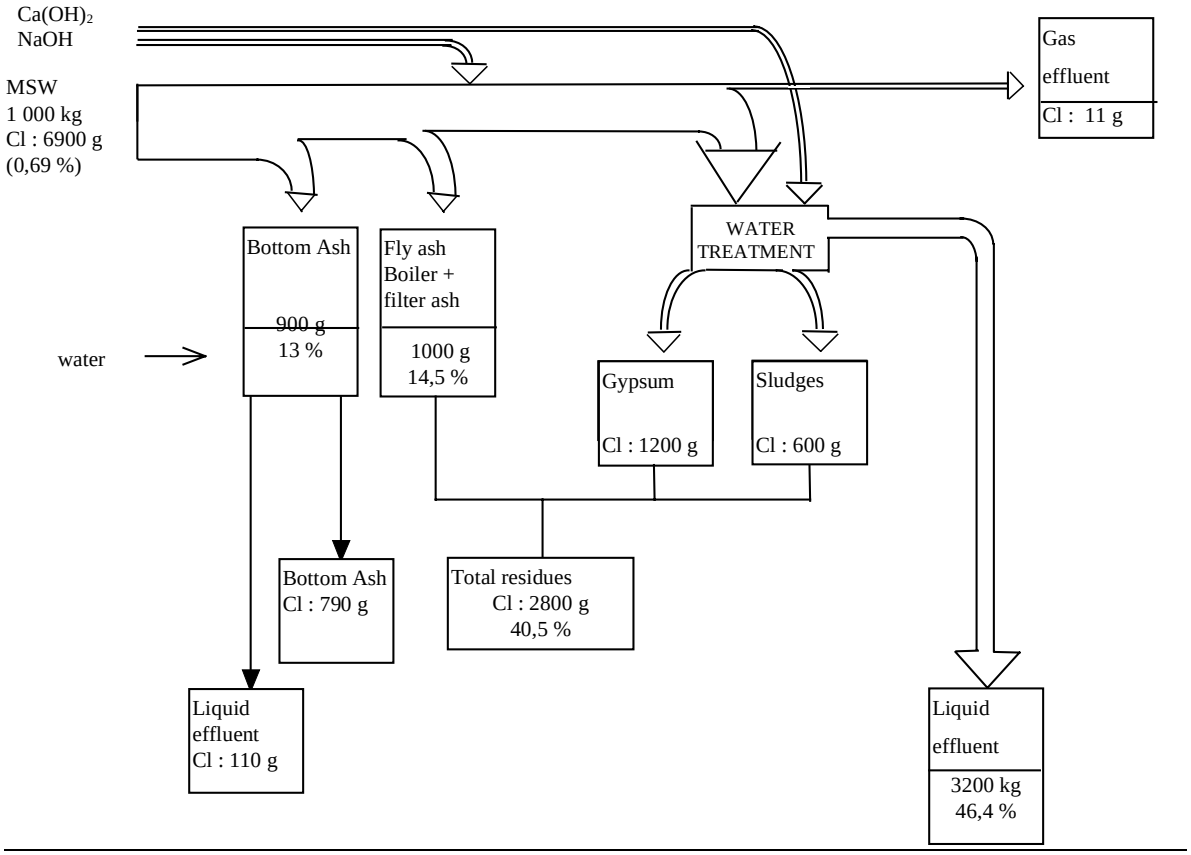
A3.2 Materials and Chlorine Distribution in Incineration - Semi-Dry Process with $Ca(OH)_2$- Würzburg Experimental Results - 1997



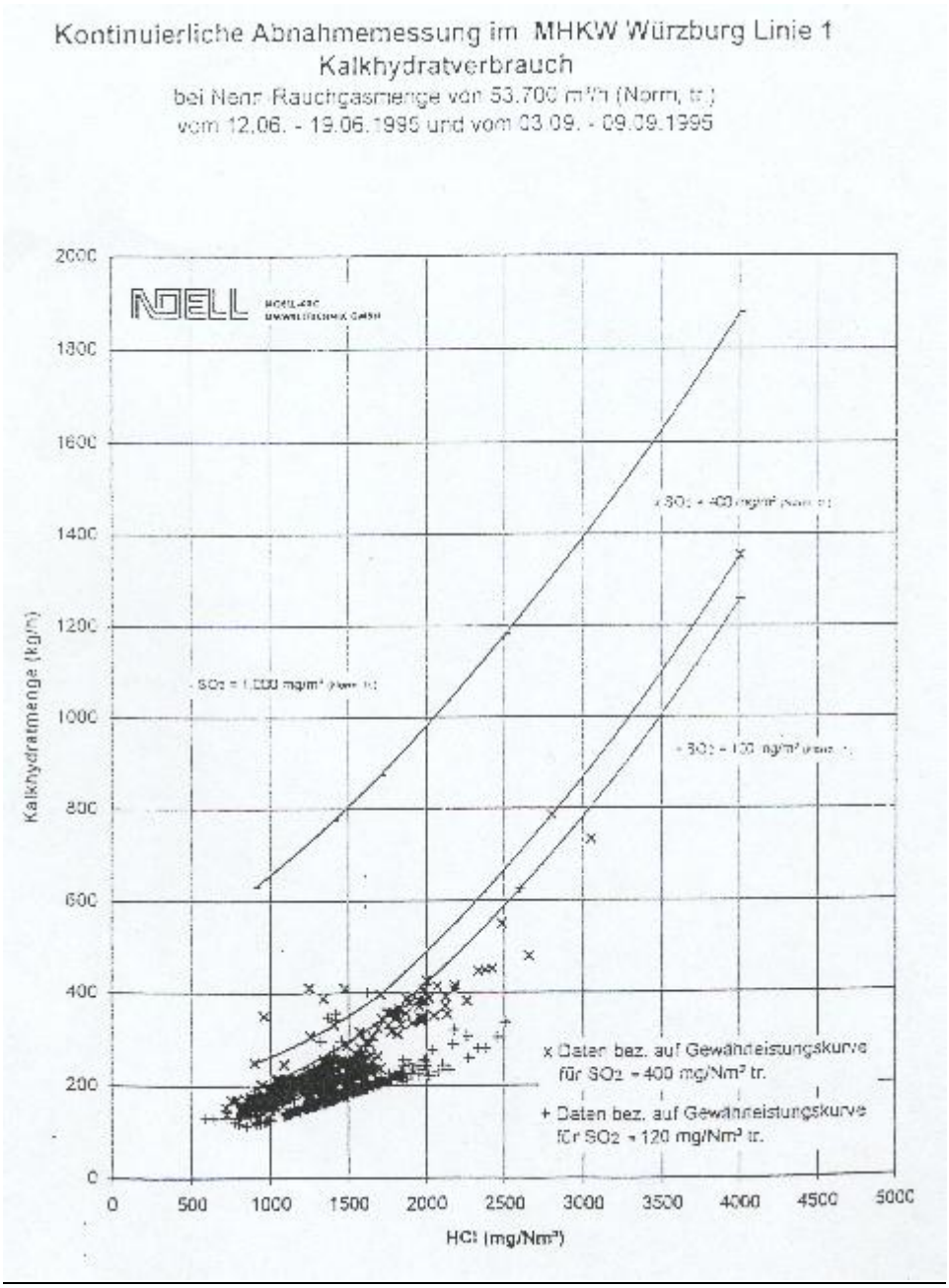


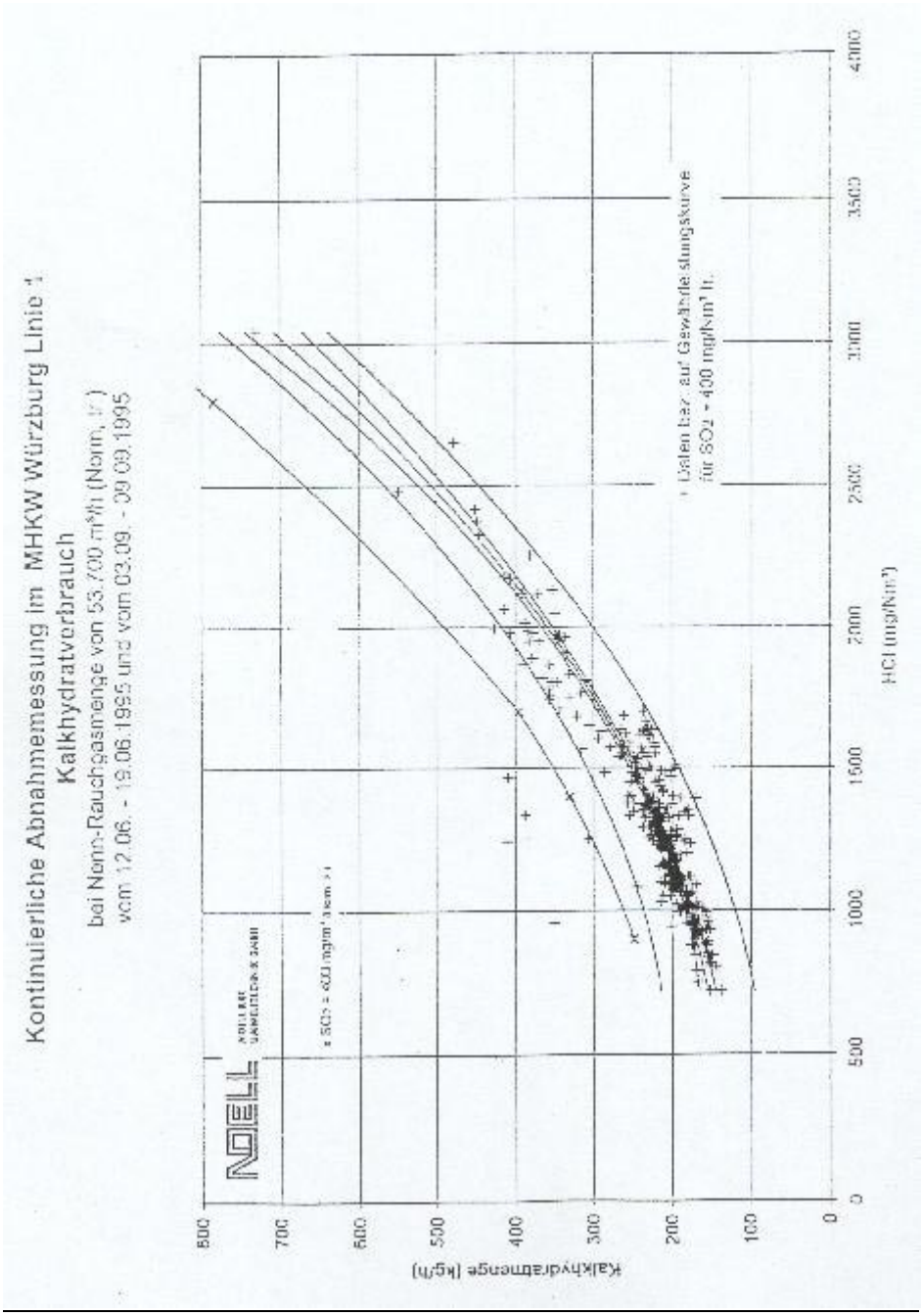
A3.4 Materials and Chlorine Distribution in Incineration - Wet Process - Bamberg Experimental Results - 1994

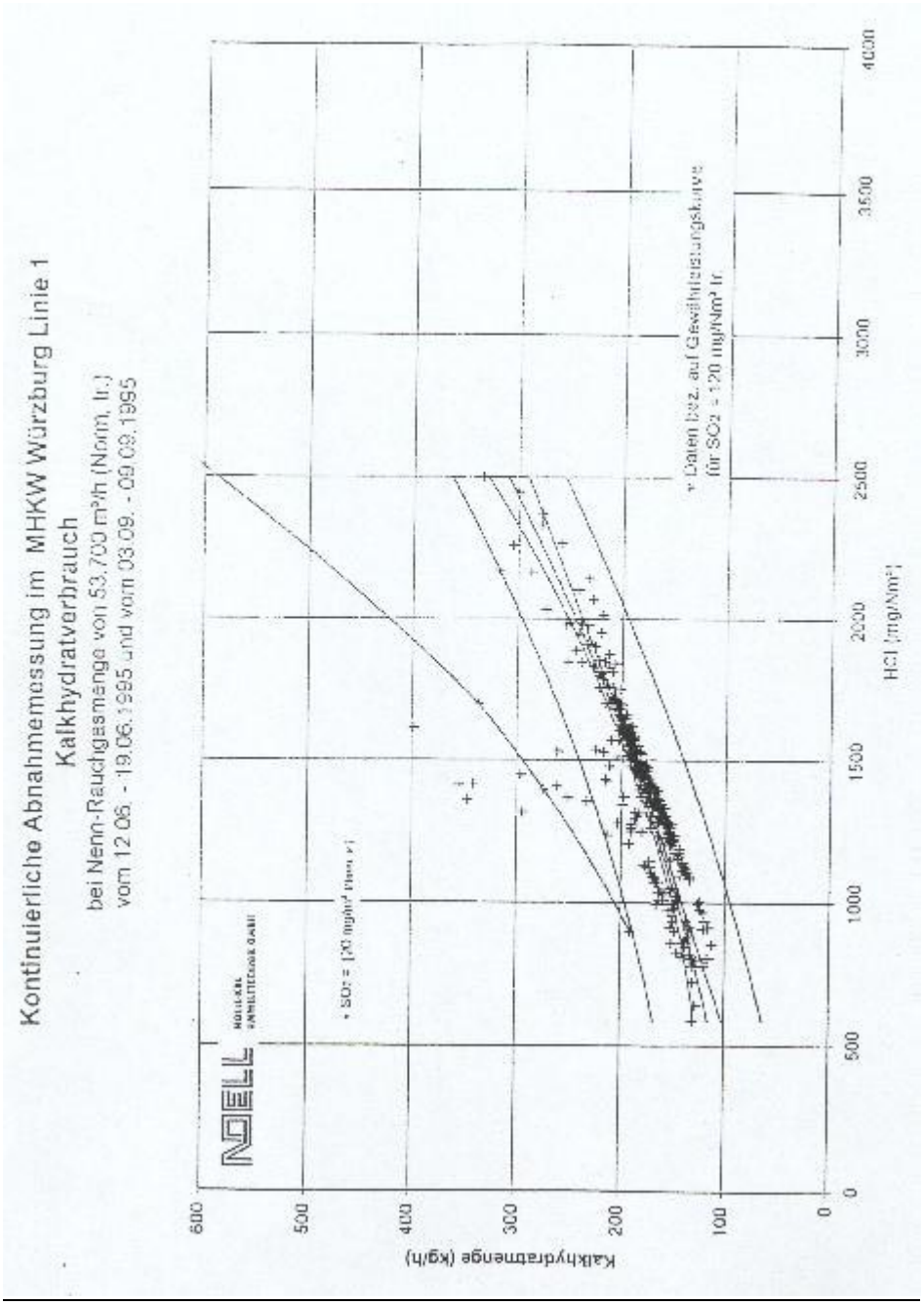




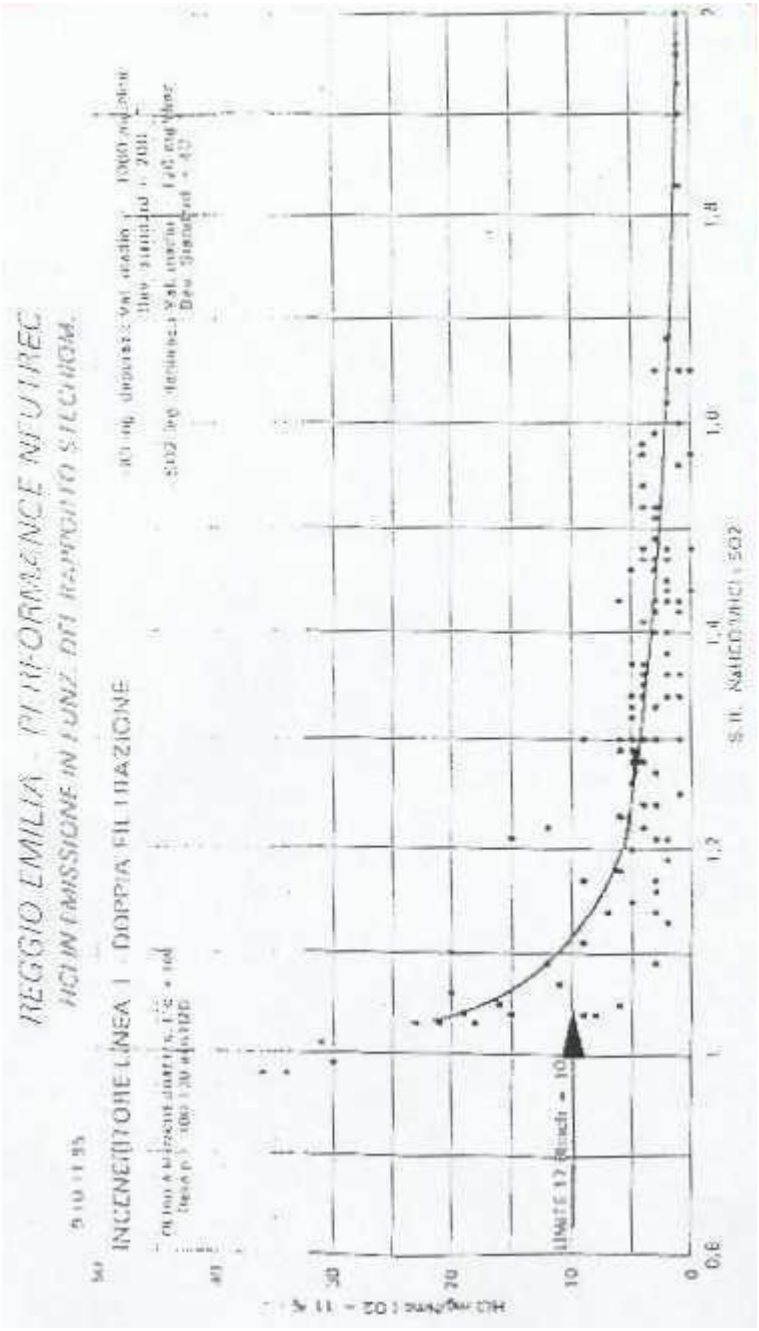
A3.5 Dry Process with Lime- Results from Würzburg 1995 - Neutralisation Agents as a function of HCl and SO_2 content in the Raw Gas




Kontinuierliche Abnahmemessung im MHKW Würzburg Linie 1
Kalkhydratverbrauch
bei Norm-Rauchgasmenge von 53.700 m³/h (Norm, tr.)
vom 12.06. - 19.06.1995 und vom 03.09. - 09.09.1995
NOELL
Kalkhydratmenge [kg/h]
HCl [mg/Nm³]
0
100
200
300
400
500
600
700
800
500
1000
1500
2000
2500
3000
3500
4000


Kontinuierliche Abnahmemessung im MHKW Würzburg Linie 1
Kalkhydratverbrauch
bei Nenn-Rauchgasmenge von 53.700 m³/h (Norm, tr.)
vom 12.06. - 19.06.1995 und vom 03.09. - 09.09.1995
MÖLL
Kalkhydratmenge (kg/h)
HCl (mg/Nm³)
0
500
1000
1500
2000
2500
3000
3500
4000
100
200
300
400
500
600

A3.6 Dry Process with Bicarbonate- Results from Reggio Emilla- 1995 - Evolution of HCl Emissions as a function of the Global Stoichiometric Ratio

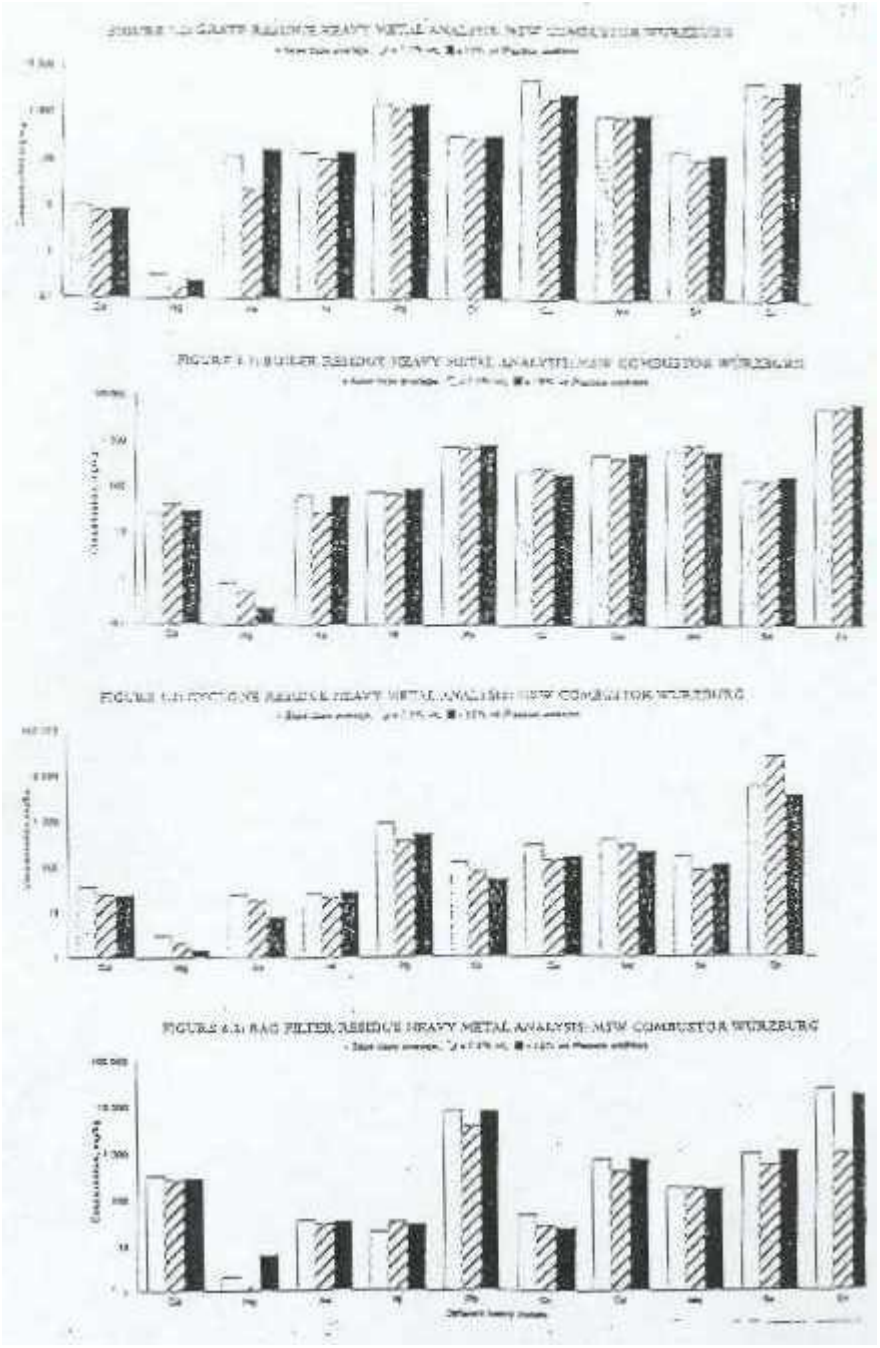


ANNEX 4

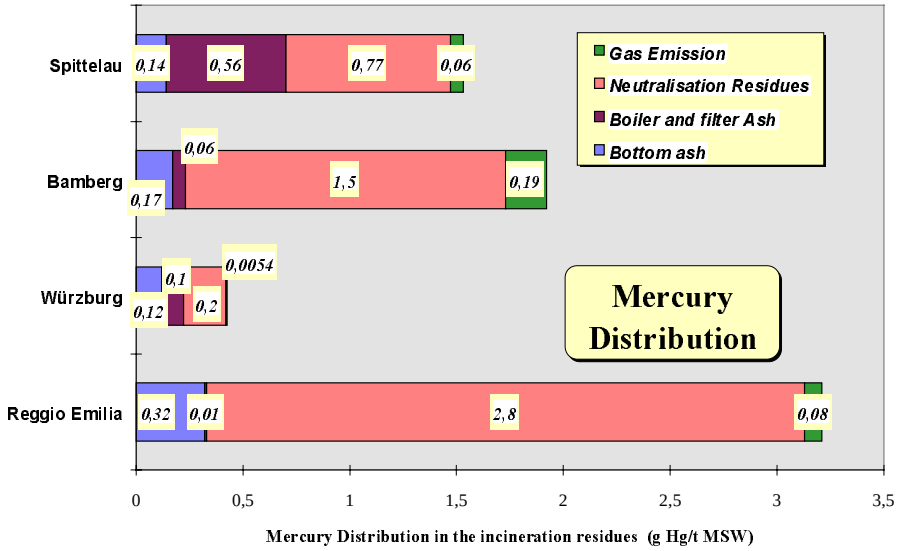
A4.1 - ANALYSIS OF FLY ASHES COLLECTED FROM DIFFERENT INCINERATORS (weight %)

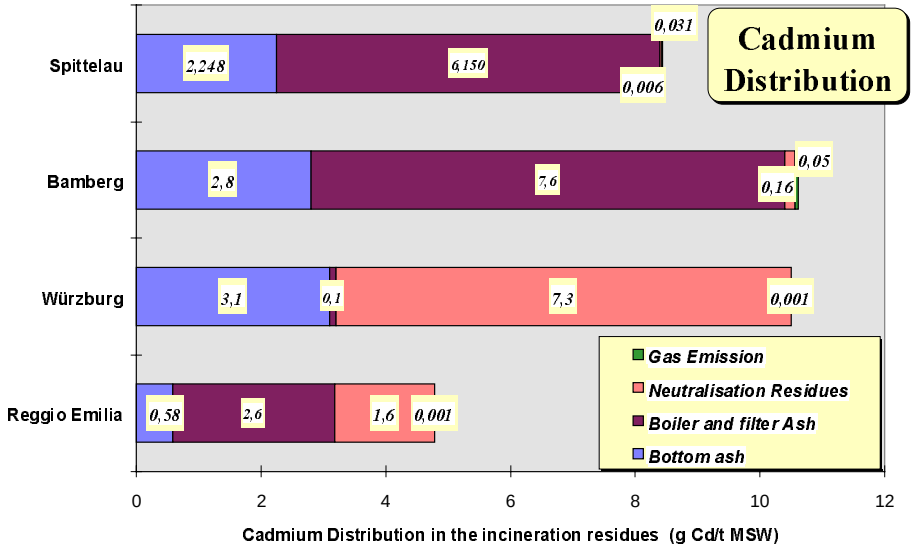
	SYTCOM 1993			A1	B1	C3	D	A2	C4	E	Lower	Upper	Average	Würzburg [Ruk98]	
% wt	min.	max.	average								values	values	values	Min.	Max.
F-															
Cl-	6.8	12.4	9.7	2.2	13.2	6.1	7.7	1.8	7.4	12.	1.8	13.2	7.2	2.8	7
CO_2-	2.9	5.7	4.1												
SO_3	5.4	20.2	8.8	9.6	6.2	7.9	5.8*	26.*	*	8.2	5.4	26	9.1		
P_2O_5	0.27	1.6	0.9	1.2	0.8	1.7	1.14	0.82	1.79	1.76	0.27	1.79	1.32		
SiO_2	16.	26.	19.	30.6	19.3	30.8	18.9	8.8	18.4	15.2	8.8	30.6	20.29		
Al_2O_3	10.2	7.2	11.9	16.7	13.6	15.4	11.7	4.	12.	8.1	4	16.7	11.64		
CaO	20.4	25.	23.1	22.	20.	17.4	19.6	7.1	18.2	16.8	7.1	25	17.3		
MgO	1.5	3.	2.5	2.5	2.8	2.7	1.8	0.72	2.2	1.58	0.72	2.8	2.04		
Na_2O	3.9	7.	5.												
K_2O	3.3	6.8	4.4												
TiO_2	1.11	1.83	1.7*	2.4	1.5	1.6	1.38	0.62	1.25	1.48	0.62	2.4	1.46		
Ba	0.05	0.2	0.11				0.08	0.09	0.08	0.15	0.05	0.2	0.06		
B	0.11	1.3	0.62												
Fe	0.21	1.4	0.85	2.3*	1.7*	1.9*	0.9	3.8	1.1	1.3	0.21	3.8	1.86		
Zn	0.09	2.84	1.25	1.	1.82	1.25	1.1	2.8	0.68	1.6	0.09	2.84	1.46		
Pb	0.34	0.95	0.54	0.4	1.2	0.74	0.41	1.6	0.26	0.65	0.26	1.6	0.75	0.06	0.14
Cu	0.04	0.099	0.076	0.1	0.11	0.11	0.05	0.08	0.04	0.09	0.04	0.11	0.08	0.02	0.05
Cr	0.009	0.05	0.025	0.07	0.04	0.06	0.04	0.026	0.032	0.08	0.009	0.08	0.05	0.01	0.03
Mn	0.23	0.072	0.046	0.09	0.11	0.11	0.04	0.048	0.053	0.09	0.04	0.23	0.08		
Cd	0.011	0.042	0.026	0.008	0.094	0.022	0.014	0.039	0.01	0.025	0.008	0.094	0.03	0.002	0.006
Hg	0.0006	0.0027	0.001											0.00004	0.0004
Ni	0.0019	0.0059	0.004				0.003	0.005	0.008	0.009	0.0019	0.009	0.0036		
Co	0.0005	0.0018	0.001				0.001		0.002		0.0005	0.002	0.0015		
As	0.0001	0.0034	0.001												
Sn														0.01	0.02
Sb														0.01	0.02

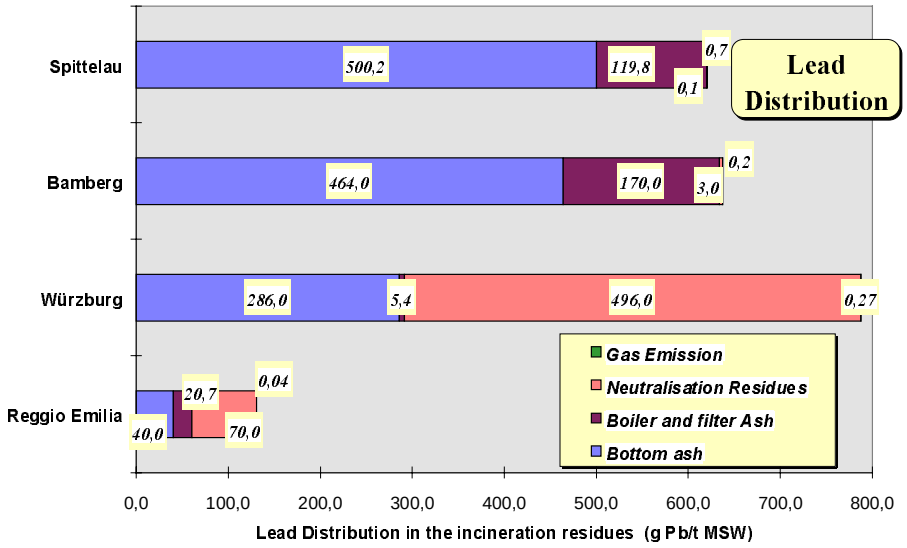
A4.2

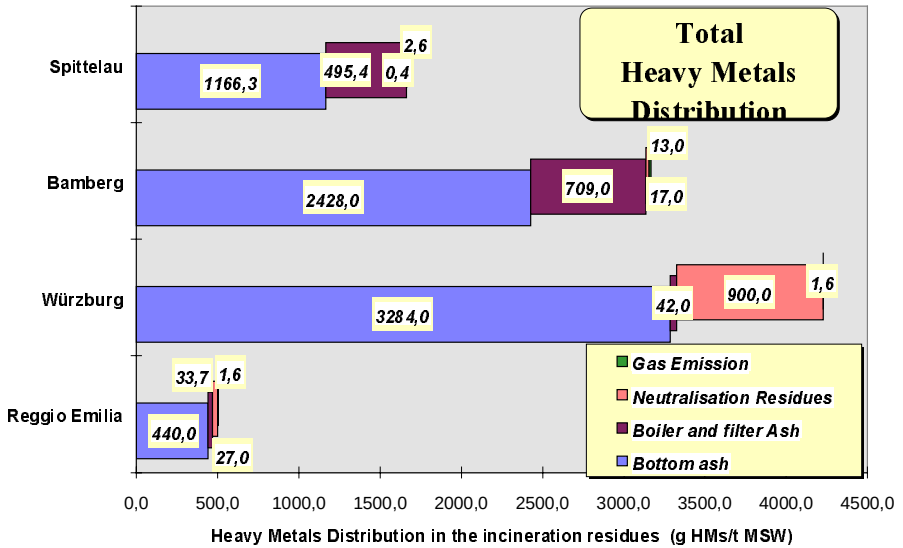


A4.3


Spittelau
Bamberg
Würzburg
Reggio Emilia
0,14
0,56
0,77
0,06
0,06
0,17
1,5
0,19
0,1
0,12
0,0054
0,2
0,32
0,01
2,8
0,08
Gas Emission
Neutralisation Residues
Boiler and filter Ash
Bottom ash
Mercury Distribution
0
0,5
1
1,5
2
2,5
3
3,5
Mercury Distribution in the incineration residues (g Hg/t MSW)


Spittelau
Bamberg
Würzburg
Reggio Emilia
2,248
6,150
0,031
0,006
2,8
7,6
0,05
0,16
3,1
0,1
7,3
0,001
0,58
2,6
1,6
0,001
Gas Emission
Neutralisation Residues
Boiler and filter Ash
Bottom ash
Cadmium Distribution
0
2
4
6
8
10
12
Cadmium Distribution in the incineration residues (g Cd/t MSW)


Spittelau
Bamberg
Würzburg
Reggio Emilia
500,2
119,8
0,7
0,1
464,0
170,0
0,2
3,0
286,0
5,4
496,0
0,27
40,0
20,7
0,04
70,0
Gas Emission
Neutralisation Residues
Boiler and filter Ash
Bottom ash
Lead Distribution
0,0
100,0
200,0
300,0
400,0
500,0
600,0
700,0
800,0
Lead Distribution in the incineration residues (g Pb/t MSW)


Spittelau
Bamberg
Würzburg
Reggio Emilia
1166,3
495,4
2,6
0,4
2428,0
709,0
13,0
17,0
328 4,0
42,0
900,0
1,6
33,7
1,6
440,0
27,0
Gas Emission
Neutralisation Residues
Boiler and filter Ash
Bottom ash
Total
Heavy Metals
Distribution
0,0
500,0
1000,0
1500,0
2000,0
2500,0
3000,0
3500,0
4000,0
4500,0
Heavy Metals Distribution in the incineration residues (g HMs/t MSW)

ANNEXE 5

DRY PROCESS WITH STANDARD GRADE LIME

HCl neutralisation

	2 HCl	**+**	**2 $Ca(OH)_2$**	**→**	**2 $Ca(OH)Cl,H_2O$**
	73		148		221
per kg of Cl	1.02		2.08		**3.1**

SO_2 neutralisation

	H_2O	**+**	**S**	**+**	**1.5O_2**	**+**	**4 $Ca(OH)_2$**	**→**	**$CaSO_4,2H_2O$**	**+**	**3 $Ca(OH)_2$**
	18		32		48		296		172		222
per kg of S			1				9.25		**5.37**		**6.93**

Concentration of Cl and S in MSW:

Cl : 7 kg/ton in presence of PVC
Cl : 3.5 kg/ton without PVC
S : 2 kg/ton

HCl and S to be neutralised :

70 % of Cl in MSW
50% of S in MSW

1. PVC is present in MSW (50% of chlorine in MSW due to PVC)

Composition of the residues(Fly Ash + Neutr. Products) kg per ton of MSW

	inlet MSW	inlet Raw Gas	Neutr. residues	Fly Ash
Cl	7	4.9		refer to
S	2	1		Table 8-1
$CaOHCl , H_2O$			14.4	
$CaSO_4 , 2 H_2O$			5.4	
$Ca(OH)_2$			6.9	
				Cd +10%

2. No PVC is incinerated

Composition of the residues(Fly Ash + Neutr. Products) kg per ton of MSW

	inlet MSW	inlet Raw Gas	Neutr. residues	Fly Ash
Cl	3.5	2.4		refer to table 8-1
S	2	1		
$CaOHCl , H_2O$			7.2	
$CaSO_4 , 2H_2O$			5.4	
$Ca(OH)_2$			6.9	

DRY PROCESS WITH SODIUM BICARBONATE

HCl neutralisation

HCl	**+**	**1.05 $NaHCO_3$**	**→**	**NaCl**	**+**	**0.025 $Na2CO_3$**	**+**	**1.025 CO_2**	**+**	**1.025 H_2O** **+**
36.5		88.2		58.5		2.65		45.1		18.45
per kg of Cl		2.48		1.65		0.075		1.27		0.52

SO_2 neutralisation

S	**+**	**1.5O_2**	**+2.4 $NaHCO_3$**	**→**	**Na_2SO_4**	**+0.2**	**Na_2CO_3**	**+**	**2.2 CO_2**	**+** **1.2 H_2O**
32		48	201.6		142		21.2		96.8	21.6
per kg of S		1.5	6.3		4.44		0.66		3.03	0.68

Concentration of Cl and S in MSW:

Cl : 7kg/ton in presence of PVC
Cl : 3.5 kg/ton without PVC
S : 2kg/ton

HCl and S to be neutralised :

70 % of Cl in MSW
50% of S in MSW

1. PVC is present in MSW (50% of chlorine in MSW due to PVC)

Composition of the residues(Fly Ash + Neutr. Products) kg per ton of MSW

	inlet MSW	inlet Raw Gas	Neutr. residues	Fly Ash
Cl	7	4.9		refer to
S	2	1		table 8-1
Na_2CO_3			1.07	
NaCl			7.59	
Na_2SO_4			4.44	
				Cd +10%

2. No PVC is incinerated

Composition of the residues(Fly Ash + Neutr. Products) kg per ton of MSW

	inlet MSW	inlet Raw Gas	Neutr. residues	Fly Ash
Cl	3.5	2.4		refer to table8-1
S	2	1		
Na_2CO_3			0.86	
NaCl			3.80	
Na_2SO_4			4.44	

SEMI - DRY PROCESS

HCl neutralisation

	2 HCl	**+**	**1.7Ca(OH)$_2$**	**→**	**CaCl$_2$,2H$_2$O**	**+**	**0.7 Ca(OH)$_2$**
	73		125.8		147		51.8
per kg of Cl	1.03		1.77		**2.07**		**0.73**

Ca(OH)$_2$ + **CaCl$_2$,2H$_2$O** → **2 CaOHCl,H$_2$O**
74 147 110.5 x 2

SO$_2$ neutralisation

	H$_2$O	**+**	**S**	**+**	**1.5O$_2$**	**+**	**4Ca(OH)$_2$**	**→**	**CaSO$_4$,2H$_2$O+**	**3 Ca(OH)$_2$**
	18		32		48		296		172	222
per kg of S			1				9.25		**5.375**	**6.93**

Concentration of Cl and S in MSW:
- Cl : 7kg/ton in presence of PVC
- Cl : 3.5 kg/ton without PVC
- S : 2kg/ton

HCl and S to be neutralised :
- 70 % of Cl in MSW
- 50% of S in MSW

1. PVC is present in MSW (50% of chlorine in MSW due to PVC)

Composition of the residues(Fly Ash + Neutr. Products) kg per ton of MSW

	inlet MSW	inlet Raw Gas	Neutr. residues		Fly Ash
Cl	7	4.9			refer to table 8-1
S	2	1			
CaCl$_2$, H$_2$O			9.9	-	
CaOHCl , H$_2$O				14.8	
CaSO$_4$, 2H$_2$O			5.4	5.4	
Ca(OH)$_2$			10.4	5.5	
					Cd +10%

2. No PVC is incinerated

Composition of the residues(Fly Ash + Neutr. Products) kg per ton of MSW

	inlet MSW	inlet Raw Gas	Neutr. residues		Fly Ash
Cl	3.5	2.7			refer to table 8-1
S	2	1			
CaCl$_2$,H$_2$O			5.4	-	
CaOHCl , H$_2$O				8.2	
CaSO$_4$, 2H$_2$O			5.4	5.4	
Ca(OH)$_2$			8.9	6.1	

					Cd +10%

WET PROCESS

HCl neutralisation

HCl	+ 0.5 NaOH	+0.275 $Ca(OH)_2$	→ 0.5 NaCl	+ 0.25 $CaCl_2$ +	H_2O	+0.025 $Ca(OH)_2$
36.5	20	20.35	29.25	27.75		1.85
2.45 (no PVC)			0.82	0.78		0.052
5.4 (PVC)			4.43	**4.2**		**0.28**

SO_2 neutralisation

H_2O	+ S	+ 1.5 O_2	+ 1.1 $Ca(OH)_2$	→ $CaSO_4$	+ 2 H_2O	+ 0.1 $Ca(OH)_2$
18	32	48	81.4	136	36	7.4
per kg of S	1		2.54	**4.3**	1.12	**0.23**

1. PVC is present in MSW (50% of chlorine in MSW due to PVC)

Composition of the residues (kg per ton of MSW)

	inlet MSW	inlet Raw Gas	Filter Cake	Liquid Effluent
Cl	7	4.9		
S	2	1		
NaCl			0	3.8
$CaSO_4$			4.3	0
H_2O			-	600l/ton MSW
$CaCl_2$			0	3.6

filter cake composition (weight : 1.25kg/ton MSW):

Compound	% weight or ppm	
As	7.6	ppm
Pb	O.12	1.5 %
Cd	54	ppm
Ca	64.8	%
Cl	1.1	%
Cr	76	ppm
F	1.5	%
C	7.3	%
Na	0.6	%
Hg	0.13	ppm
S	24.2	%
Zn	0.19	%

2. No PVC is incinerated

Composition of the residues (kg per ton of MSW)

	inlet MSW	inlet Raw Gas	Filter Cake	Liquid Effluent
Cl	3.5	2.4		
S	2	1		
NaCl			0	1.9
$CaSO_4$			4.3	0

H_2O			-	600l/ton MSW
$CaCl_2$			0	1.8

SEMI-WET - WET PROCESS

With no water-treatment of the liquid effluent prior its evaporation in the semi-wet step

HCl neutralisation

HCl	**+ 0.5 NaOH**	**+0.275 $Ca(OH)_2$**	**→**	**0.5 NaCl**	**+**	**0.25$CaCl_2,2H_2O$**	**+0.5H_2O**	**+0.025$Ca(OH)_2$**	
36.5	22	20.35		29.25		36.75	9	1.85	
perkg/Cl	0.62	0.57		0.82		1.03	0.25	0.05	

$Ca(OH)_2$	**+**	**$CaCl_2,2H_2O$**	**→**	**2CaOHCl,H_2O**
74		147		2x110.5

SO_2 neutralisation

H_2O	**+**	**S**	**+**	**1.5O_2**	**+**	**1.1$Ca(OH)_2$**	**→**	**$CaSO_4,2H_2O$**	**+**	**0.1$Ca(OH)_2$**
18		32		48		81.4		172		7.4
per kg of S		1				2.54		**5.375**		**0.23**

1. PVC is present in MSW (50% of chlorine in MSW due to PVC)

Composition of the residues (kg per ton of MSW)

	inlet MSW	**inlet Raw Gas**	**Solid Residue**	
Cl	7	4.9		
S	2	1		
NaCl			3.8	3.8
$CaSO_4,2H_2O$			5.4	5.4
CaOHCl,H_2O				1.3
$CaCl_2,2H_2O$			4.7	3.9
$Ca(OH)_2$			0.5	

filter cake composition (weight : 1.25kg/ton MSW):

Compound	% weight or ppm	
As	7.6	ppm
Pb	O.12	1.5
	%	
Cd	54	ppm
Ca	64.8	%
Cl	1.1	%
Cr	76	ppm
F	1.5	%
C	7.3	%
Na	0.6	%
Hg	0.13	ppm
S	24.2	%
Zn	0.19	%

2. No PVC is incinerated

Composition of the residues (kg per ton of MSW)

	inlet MSW	**inlet Raw Gas**	**Solid Residue**	
Cl	3.5	2.4		
S	2	1		
NaCl			1.9	1.9
$CaSO_4$, $2H_2O$			5.4	5.4
CaOHCl,H_2O				0.6
$CaCl_2,2H_2O$			2.4	2

$Ca(OH)_2$			0.2	

ANNEX 6

Elemental composition of APC residues from MSW incinerators

A.6.1. – Total concentrations of major and minor elements measured in APC residues from various countries. n = number of different samples (source: IAW97).

Residue	Element	Mean (mg/kg)	Median (mg/kg)	25%-75% percentile range (mg/kg)	n
Fly ash	Ca	107000	107000	95000 - 120000	20
	Cl	74000	50000	40000 - 102000	24
	Si	160000	170000	130000 - 180000	14
	Mg	15000	15000	14000 - 17000	15
	Fe	25000	23000	18000 - 33000	20
	Al	71000	73000	59000 - 81000	18
	K	36000	34000	30000 - 41000	19
	Na	31000	29000	23000 - 38000	17
	Zn	28000	22000	16000 - 35000	26
	S	26000	27000	21000 - 33000	20
	Pb	11000	7800	6300 - 15000	25
	Ti	8700	8700	7500 - 9400	17
	Mn	1300	1200	1000 - 1600	19
	Ba	1700	1700	940 - 2600	18
	Sn	1400	1500	860 - 1800	15
	Cu	1200	1100	930 - 1300	25
Dry and semidry residues with fly ash	Ca	230000	222000	180000 - 280000	19
	Cl	180000	160000	91000 - 222000	23
	Si	69000	63000	51000 - 92000	12
	Mg	9400	8800	7400 - 12000	16
	Fe	12000	9100	63000 - 11000	19
	Al	26000	19000	15000 - 29000	27
	K	23000	24000	15000 - 31000	18
	Na	17000	15000	12000 - 20000	16
	Zn	15000	16000	12000 - 18000	28
	S	15000	17000	8200 - 21000	18
	Pb	5400	5600	4100 - 6300	27
	Ti	3300	3200	2600 - 4400	17
	Mn	480	440	280 - 680	19
	Ba	540	450	320 - 660	18
	Sn	890	840	770 - 1000	15
	Cu	710	630	490 - 860	25
Sludge from treatment of wastewater from the wet process (without fly ash)	Ca	150000	160000	87000 - 200000	3
	Cl	36000	38000	26000 - 47000	4
	Si	78000	-	-	1
	Mg	75000	36000	19000 - 170000	3
	Fe	54000	45000	20000 - 97000	3
	Al	28000	25000	21000 - 39000	3
	K	3900	2300	810 - 8600	3
	Na	1900	1700	720 - 3400	3
	Zn	31000	29000	15000 - 45000	12
	S	4400	-	2700 6000	2
	Pb	11000	9700	4400 - 19000	12
	Ti	2600	2200	1400 - 4300	3
	Mn	9100	10000	5400 - 12000	3
	Ba	460	200	87 - 670	11
	Sn	400	-	340 - 450	2
	Cu	1200	900	760 - 1700	12

A.6.2 - Total concentrations of trace elements measured in APC residues from various countries. n = number of different samples (source: IAW97).

Residue	Element	Mean (mg/kg)	Median (mg/kg)	25%-75% percentile range (mg/kg)	n
Fly ash	Hg	8,0	6,0	2,3 - 10	17
	Cd	390	290	240 - 480	26
	Sb	530	450	340 - 690	12
	Cr	650	730	430 - 840	26
	Sr	280	250	140 - 400	12
	Ni	140	110	91 - 110	25
	As	130	130	49 - 200	17
	V	51	45	32 - 63	15
	Ag	55	53	33 - 75	10
	Co	51	54	30 - 69	17
	Mo	40	30	25 - 37	13
	Se	14	12	11 - 18	12
Dry and semidry residues with fly ash	Hg	15	12	8,4 - 18	28
	Cd	300	260	190 - 360	28
	Sb	790	820	630 - 940	13
	Cr	180	140	110 - 220	28
	Sr	460	400	400 - 500	6
	Ni	94	30	23 - 60	25
	As	170	170	120 - 210	26
	V	33	31	19 - 50	6
	Ag	22	14	1,1 - 49	11
	Co	9,6	9,0	6,0 - 15	11
	Mo	15	15	11 - 20	11
	Se	8,2	7,0	4,8 - 11	23
Sludge from treatment of wastewater from the wet process (without fly ash)	Hg	650	660	240 - 790	12
	Cd	630	660	290 - 880	12
	Sb	140	-	80 - 200	2
	Cr	240	210	130 - 340	12
	Sr	104	85	52 - 130	10
	Ni	62	36	26 - 53	12
	As	89	72	49 - 110	12
	V	47	31	25 - 86	3
	Co	9,8	9,7	4,8 - 16	12
	Mo	12	6,0	3,0 - 24	11

A.6.3A – Accumulated leached amounts of components found by combined column and batch leaching tests. The results show the amounts leached in mg/kg for L/S = 0-25 l/kg.

Komponent	Fly ash	Dry and semidry residues with fly asht	Wet scrubber sludge + fly ash
TDS	210000 – 230000	290000 - 380000	140000
Ca	9100 – 24000	61000 - 109000	17000
Na	23000 – 30000	12000 - 17000	21000
K	28000 – 50000	17000 - 29000	21000
Cl^-	89000 – 106000	116000 - 200000	56000
SO_4^{2-}	13000 – 41000	470 - 3100	32000
As	0,10 - 0,19	< 0,02 - 0,04	0,28
Cd	0,051 - 35	0,03 - 0,44	< 0,0006
Cr	0,053 - 0,12	< 0,6 - 2,4	0,52
Cu	0,026 - 0,31	0,13 - 22	< 0,004
Hg	< 0,013	< 0,003	< 0,001
Mo	7,1 - 14	1,1 - 3,0	12
Ni	< 0,013	< 0,2	< 0,2
Pb	17 - 370	220 - 3400	< 0,0011
Zn	< 1,4 - 580	45 - 340	0,15
NVOC	14 - 46	71 - 780	78

Sources:

Hjelmar, O. (1992): Residues from acid flue gas cleaning at MSWIs II: Experimental work. Environmental Report No. 193. Danish Environmental Protection Agency .

Hjelmar, O. (1993): Leaching of fly ash from MSWIs. Report prepared for the Danish Environmental Protection Agency. VKI, Hørsholm, Denmark.

More detailed data from the above sources were used together with yet unpublished VKI (1998) data on the leaching of various components from MSWI fly ash in column tests for the scenario calculations in Section 10.5.

A.6.3B - Range of variation of composition of leachate from APC residues in 2 landfill cells at AV Miljø in Denmark.

Parameter	Enhed	Dry and semidry residues with fly ash 1989 - 1995	Wet scrubber residues with fly ash 1994 –1995
pH	-	6,6 - 10,9	7,1 - 7,7
TDS	mg/l	66000 - 190000	32000 - 150000
SS	mg/l	140 - 1500	87 - 110
Conductivity	mS/m	780 - 17000	4900 - 16000
Sulphate	mg/l	160 - 1300	980 - 1900
Chloride	mg/l	2300 - 110000	3300 - 82000
K	mg/l	65 - 18000	7100 - 35000
Ca	mg/l	250 - 45000	1400 - 4100
Cd	mg/l	0,005 - 7,3	0,23 - 2,3
Cr	mg/l	0,003 - 0,98	0,026 - 0,3
Cu	mg/l	0,004 - 0,53	0,0006 - 0,017
Fe	mg/l	0,15 - 3	0,03 - 0,75
Hg	mg/l	< 0,0005 - 0,0029	< 0,0005 - 0,002
Ni	mg/l	< 0,01 - 0,15	< 0,01 - 0,05
Pb	mg/l	0,04 - 1600	0,12 - 1,3
Zn	mg/l	< 0,01 - 7,6	0,09 - 0,43

Sources:

AV Miljø (1996): Annual report 1995. AV Miljø, Avedøre Holme, Hvidovre, Denmark .

Flyvbjerg, J. & O. Hjelmar (1997): APC residues from municipal solid waste incinerators 3. Survey of the possibilities of recovery, treatment, utilization and disposal. Arbejdsrapport fra Miljøstyrelsen nr. 92. The Danish Environmental Protection Agency, Copenhagen, Denmarkl .