CHAPTER 5 - REGULATION OF MSW INCINERATORS

During incineration, most organic-based materials are destroyed by complete oxidation to carbon dioxide and water vapour but inorganics remain substantially untouched. Inorganics either partition within the various residue streams or are entrained into the flue gas stream. As noted in the previous chapter, considerable work has been undertaken in the past 10 to 15 years to reduce the level of emissions to the atmosphere through the stack. This has resulted in the application of new APC technologies incorporating both new operating philosophies and new equipment. These changes have influenced the characteristics of the residue streams. For instance, the use of lime to remove acid gases has increased the mass of the fine residue generated in the systems which, in turn, has increased the alkalinity of this material, thereby influencing the potential solubility of trace metals in the disposal site. APC technologies based on wet scrubbers generate less solid residues, but they generate a wastewater stream requiring treatment. To address the regulatory concerns, various jurisdictions have developed specific MSW incineration regulations governing air emissions, residue disposal, and wastewater treatment. This chapter reviews these regulations.

Regulations represent an evolving set of limits on the operation of MSW incinerators. Newer limits are more stringent and comprehensive in response to requirements that are aimed at controlling an increasing number of substances (contaminants). Each jurisdiction has adopted standards they consider appropriate for their circumstances. Typically, both the toxicity and persistence of contaminants in the environment are considered during the evaluation process. Examples of the contaminants that could be considered are shown in Table 5.1. This list was derived from the Canadian MSW incinerator operating guidelines (CCME, 1989). The contaminants listed cover the broad range from combustion related gas emissions to trace metallic and organic compounds.

As noted in an earlier chapter, changes to the operational characteristics of a facility can influence atmospheric emissions and consequently influence the characteristics of the residues. Regulations governing the design and operation of MSW incineration facilities to minimise air emissions address both:

- operational factors such as combustion conditions; and,
- the quantity of materials released through the stack.

Emission standards exist in many jurisdictions but they are not presented on a consistent basis. Both temperature and diluent concentration can vary between jurisdictions. The values in this report have been corrected to 11% O_2 and reference conditions of dry gas at 25°C and 101.3 kPa pressure. (Note: The comparative diluent and temperature correction used in the United States is 7% oxygen and 68°F. Thus, while the Ontario and US emission concentrations are equivalent, when comparing the two standards with their normal diluent basis, the Ontario values would appear to be

Table 5.1
List of Air Emission Contaminants

Acid Gases

- Hydrogen chloride
- Hydrogen fluoride
- Oxides of nitrogen
- Oxides of sulphur

Trace Metals

*Cd - Cadmium	*V - Vanadium	K - Potassium	Co - Cobalt
Fe - Iron	Si - Silicon	*Hg - Mercury	*Se - Selenium
*Be - Beryllium	Al - Aluminum	Na - Sodium	*Cu - Copper
*Pb - Lead	Ti - Titanium	*As - Arsenic	Te - Tellurium
Mo - Molybdenum	Mg - Magnesium	*Zn - Zinc	Ag - Silver
*Cr - Chromium	B - Boron	*Sb - Antimony	Sn - Tin
Ca - Calcium	Ba - Barium	Mn - Manganese	
*Ni - Nickel	P - Phosphorous	Bi - Bismuth	

*metals selected by the committee as most important for health and the environment.

Organics

Polychlorinated dibenzo-p-dioxin (PCDD) homologues

TCDD	tetra
PeCDF	penta
HxCDF	hexa
HpCDD	hepta
OCDD	octa

Polychlorinated dibenzo-furan (PCDF) homologues

TCDF	tetra
PeCDF	penta
HxCDF	hexa
HpCDF	hepta
OCDF	octa

Chlorobenzenes (CB)

Cl-2 benzenes
Cl-3 benzenes
Cl-4 benzenes
Cl-5 benzenes
Cl-6 benzene

Polychlorinated Biphenyls (PCB)

Chlorophenols (CP)

Cl-2 phenols
Cl-3 phenols
Cl-4 phenols
Cl-5 phenol

Polyaromatic Hydrocarbons (PAH)

Acenaphthylene
Acenaphthene
Fluorene
Phenanthrene
Anthracene
Fluoranthene
Pyrene
Chrysene
Benzanthracene
Benzo(e)pyrene
Benzo(a)pyrene
Benzo(b,k)fluoranthene
Perylene
o-Phenylenepyrene
Dibenzo(a,h)anthracene
Benzo(g,h,i)perylene

Other

Particulate matter	Carbon monoxide	Oxygen or
Opacity	Total hydrocarbons	Carbon dioxide

After CCME, 1989

about 70% of the U.S. levels.) Wet standard levels are converted to dry, assuming the average moisture level will be 20%.

Residue treatment and disposal regulations exist in many jurisdictions. The scope of these can vary from requirements for disposal under controlled conditions to quality standards such as the level of carbon in the material being disposed. Some jurisdictions have developed regulations governing the utilisation of residues. Both these issues are discussed later in this chapter. Wastewater treatment aspects of the disposal of wet APC residues is not discussed because, for the most part, these regulatory requirements do not specifically address wastewater discharges from MSW incineration facilities.

5.1 EXISTING MSW INCINERATOR OPERATING GUIDELINES

Operational guidelines have been developed to assist regulators in standardising the design parameters of incinerator facilities. A summary of typical conditions is provided in Table 5.2. The intent of these standards is to ensure good combustion conditions and minimal organic emissions. The design guidelines are based upon theoretical calculations of the combustion process. In some cases, the applicability of these calculations is influenced by new trends in technology. In addition, some regulations stipulate the objectives for incineration. For example, German regulations mandate the recovery of energy from MSW incinerators; no systems are used solely to incinerate waste.

5.1.1 Furnace Temperature and Residence Time

The operating temperature concept used in North America was developed from hazardous waste incinerator test data and some now suggest that such standards may be inappropriate for MSW systems. Because the reactions needed to take the combustion process to completion occur very quickly, if the temperature is sufficient and there is enough oxygen, these restraints on temperature and residence time may be artificial and can limit the development of new technologies. Thus, while there is a regulatory move to relax the prescriptive design aspects for MSW incinerator regulations, staff charged with the responsibility of making decisions on applications still find the guidance of these standards helpful.

When considering temperature values in the table it should be remembered that some of the apparent differences result from conversion between various temperature units. The value 982°C represents 1800°F, a common value for the United States whereas, Canada and the European countries specify temperatures in °C and choose 1000°C as a suitable number. Both numbers are within the accuracy obtainable from conventional measurement systems.

Table 5.2
Incinerator Operating Conditions

Jurisdiction	Temperature (°C)	Residence Time (Seconds)	Minimum Excess Oxygen	CO Level (mg/Rm^3 @ 11% O_2)				APC Operating Temperature (°C)
				Averaging Times	1 hour	4 hours	24 hours	
U.S. 1991						see note	see note	17 > max. test temp.
California Guidelines	982	1		300 (none specified)				
Pennsylvania BAT Criteria	982	1		300 (8 hour)				
New Jersey Guidelines	815	1	6		300			
CCME Guidelines	1000	1	6/RDF 3			57/114		140
Peel, Ontario Permit	1000	1	6			57		140
B.C. Guideline	1000	1	6/RDF 3			55/110		140
Ontario A7 Guidelines 1995	1000	1						
European Community Guidelines	850	2	6		100		50	
Germany	850	2	6	90% of readings <150 (24 hours)	100		50	
United Kingdom	850	2	6					
Denmark	850	2	6	620 (10 minute) 825 (1 minute)			165	
Netherlands	850	2	6				50	
France	850	2	7				50	
Belgium	800	1	6				1000	
Italy	950	2						
Norway	800	1.5					100	
Sweden (<6 tph) (>6 tph)	850 850	- 2	6 6	105 (1 hour) 105 (1 hour)				
Japanese Guideline 1990	800	2	6			69		200

Notes: Under carbon monoxide the US Regulations distinguish between incinerator types. Under 4 hour averaging times: 40 (35 ppmdv) refers to modular units; 80 (70 ppmdv) to mass burn waterwall or refractory wall, and, fluidised bed units; and, 120 (105 ppmdv) to RDF mixed with pulverised coal units. Standards for both new and existing facilities are identical. Under the 24 hour averaging time category: existing units are limited to 80(70 ppmdv) for mass burn rotary refractory units; 160 (140 ppmdv) for RDF spreader stokers with or without coal and 200 (175 ppmdv) for mass burn rotary waterwall systems. For for new plants the 24 hour average for all RDF systems except Mass Burn Rotary Waterwall are limited to 120 (105 ppmdv) for CO with the MBWW Rotary units having a limit of 80 (70 ppmdv).

Residence time specifications vary from the stringent 1 second residence time at 1000°C specified in Ontario Guideline A-7, to a more flexible approach such as that favored by some European countries. The Ontario guideline provides a definition of the zone where 1000°C could be expected to occur. Europeans require a longer time at lower temperatures to allow some flexibility in design. Germany has gone one step further in the latest documents, (17 BImSchV; November, 1990). That regulation states that if testing data collected at the specified conditions is the same as that collected at lower temperatures or shorter residence times, the facility can be operated at the lower level.

5.1.2 Combustion Efficiency and Carbon Monoxide

Carbon monoxide (CO) operating levels are used as a surrogate for good combustion conditions. They also are used to calculate various combustion efficiency factors. In some jurisdictions combustion efficiency may be defined as the ratio of CO to the sum of CO and CO_2; in others it may be the ratio of CO to CO_2. Because CO can be measured directly, the trend is towards setting a standard for CO levels at the boiler exit. CO standards are contained in Table 4.3.

Averaging time variations are evident in the CO standards. The Danish standards are for 10-minutes and 1-minute respectively. The latest German standards specify three values based upon differing averaging times for CO. The 24-hour or daily mean must be 50 mg/m^3; with an hourly mean of 100 mg/m^3; and, 90% of all readings in the 24 hour period being less than 150 mg/m^3. The German values are not considered emission values but rather used as an operational parameter.

Where additional values are shown under the 4-hour category in Table 5.2, they are explained in the footnote. Notable by its absence is the lack of a carbon monoxide standard in the new Ontario Guideline A-7. It should be recognized that under the operating procedures in the province, each new facility will have a specific Certificate of Approval that will specify operating parameters of this nature. These numbers can be tailored for different combustion technologies thereby reducing the complexity of the new guideline.

5.1.3 APC Temperatures

Performance of the air pollution control systems has been found to be correlated with temperature at the inlet to the APC (NITEP, 1986). Some jurisdictions are recommending operating temperature restrictions on these systems. The aim is to lower the temperature to increase the trace contaminant and acid gas removal efficiency while maintaining temperatures high enough to minimize corrosion in the system and blinding of the fabric filters. At low temperatures the hygroscopic nature of the reaction products of the sorbent injection systems can lead to formation of 'mud-

like' material that coats the bags and turns to a solid non-porous mass. Canada included a maximum inlet operating temperature recommendation in the CCME (1989) document. The 1995 US regulations specify that the facility cannot be operated with an inlet temperature to the last particulate control device in the APC that is any higher than 17°C more than the 4-hour block average during the most recent successful dioxin test period.

5.1.4 Other Aspects

There are other design related parameters such as capacity, (throughput) and auxiliary fossil fuel fired burner capacities included in some regulations.

During operation, incinerators are subject to upset if the loading rate is too variable or too far from the design point. Limitations on feed rate are included in some standards including the 1995 U.S. standards which limit loading to no more than 10% above that used during the last test series. This is to prevent excessive particulate entrainment and potential trace organic formation downstream of the combustion chamber (US EPA, 1995BID).

The German, Dutch and English regulations and others require that the system be equipped with auxiliary burners to enable the furnace to reach operating temperature before MSW is added, and to maintain combustion efficiency in the event of a drop in fuel level in the system.

Several jurisdictions have added staff/operator training requirements to regulations. The new US EPA rules require ASME certification of senior staff; British Columbia MOE's proposal requires that all staff be trained to a level acceptable to the Ministry. Owners of MSW incineration facilities attempt to hire staff who have previous experience at similar facilities. Lead operators generally have such experience and others on staff are promoted to positions of increased responsibility if they have appropriate qualifications and sufficient time in the facility.

5.2 AIR EMISSION STANDARDS

The operating emissions from a facility are related to both the type of APC system installed and the nature of the MSW received at the facility. Generally, the greater the efficiency of the APC system, the lower the emissions, although the presence of commercial or industrial type waste in the fuel stream may raise trace contaminant levels in the emissions. Regulators set performance standards based upon their desire to minimise emissions; however, these standards vary from jurisdiction to jurisdiction based upon the perceived requirements in that area and their regulatory interpretation of the issues discussed earlier. This section reviews existing regulations for several groups of emissions:

- conventional combustion products and acid gases
- trace metals
- trace organics.

Regulatory limits can be based upon either the absolute emission number or a removal efficiency determined by the ratio of emissions to input to the APC device. Other variations in the standard setting process include the use of various averaging protocols based either on the time of sampling or the number of samples taken. While the following summarises some of these issues, no attempt has been made to address the differences in sampling times, rather the data are normalised to standard temperature and pressure and a standard basis diluent concentration of 11% O_2.

5.2.1 Chronological Changes in Emission Standards

As noted in the introduction, newer standards tend to be more stringent. Table 5.3 illustrates the trends for emission standards of conventional pollutants in those countries where the data are easily traced. Regulations in the United States have had numerous changes since 1989. They are extremely complex, given that they were written to address different technologies and sizes of facilities, but all exhibit the same decreasing trends in emissions.

Table 5.3
Chronology of Municipal Solid Waste Incinerator Emissions Limits - Combustion Products and Acid Gases (Values expressed as mg/Rm^3 @ 11% O_2)

Jurisdiction (Country/State/Prov.)		Hydrogen Chloride	Hydrogen Fluoride	Sulphur Dioxide	Oxides of Nitrogen	Particulate Matter	Carbon Monoxide	Hydrocarbons (as CH_4)
France	1982	120				200	1530	11
	1986	155				78	1900	
Netherlands	1984	1080	23	690	290	120		
	1989	9	1	37	65	5	46	9
Switzerland	1986	28	4	460	460	46	92	
	1991	18	2	46	74	9	46	18
Germany	1986	46	2	90	460	32	92	18
1990 mean 24 hour		9	1	46	184	9	46	9 (as carbon only)
Denmark	1986	83	2	240		33	83	13
	1991	60	2	276		37	92	18
Sweden	1994	50	2	240		30	100	20 *
	Proposed	10	1	50	200	10	50 (daily)	10 (total carbon)

* = as total carbon for old plants

Four major standards are currently enforced: the Canadian (CCME, 1989); European Economic Community (EEC, 1989); German (17 BImSchV, 1990); and the U.S. (EPA, 1995). A summary of these standards and those from other jurisdictions is presented in Table 5.4. As noted above, the US EPA standards have evolved since the late 1980's and those in the table represent the latest edition. These regulations are currently being challenged in the U.S. court system and may be subject to revision.

The EEC Directive sets out minimum standards for MSW incinerators in all countries of the EEC. All new facilities, as of December 1, 1990, are required to meet the standards, whereas existing large facilities have until December 1996 to comply. Interim standards on facilities smaller than 6 tonnes per hour applied in December 1995, forcing local standards to adjust by 1996.

The Germans have added other requirements to the EEC Directive noting that existing installations needed to comply by March 1994, and absolute compliance must occur by December 1996. The rule allows local jurisdictions some discretion in requiring tighter controls where necessary to protect the environment, while still allowing flexibility in operating conditions where it can be demonstrated that the alternative operating conditions do not have a detrimental impact on the quality of air emissions.

The newest U.S. regulations were passed into law in late 1995. They apply across the country and set a minimum performance standard in much the same manner as the European Directive. These standards require compliance at existing facilities by 2000, but states have the ability to accelerate compliance by including these standards in state regulations. The current court challenge relates to the distinction between different sizes of facilities included in the standards and the absolute limits that will apply to some of the existing smaller facilities.

The Canadian CCME guideline was developed by a joint federal/provincial committee and was meant to act as a basis for provincial regulations for new MSW incinerators in Canada. The new Ontario guideline applies only to new facilities built after December, 1995. The guidelines do not apply to existing facilities in Ontario unless they undergo modification or expansion. Currently these facilities have specific operating permits which contain marginally higher emission standards. As mentioned earlier, these specific permits allow more stringent standards to be set for specific facilities if necessary.

As is the situation in Canada, all countries tend to view national standards as minimum operating levels. Local jurisdictions can apply more stringent standards. These are reflected in facility specific operating permits and thus there appear to be a plethora of standards in some countries when, in fact, the operating limits at a particular facility reflects the requirements of the local area.

Table 5.4
Municipal Solid Waste Incinerator Emissions Limits - Combustion Products and Acid Gases (mg/Rm^3 @ 11% O_2)

Jurisdiction (Country/State/Prov.)		Hydrogen Chloride	Hydrogen Fluoride	Sulphur Dioxide	Oxides of Nitrogen	Particulate Matter	Carbon Monoxide	Hydrocarbons (as CH_4)
European Economic Community 1991		46	2	276		28	92	18
Italy 1991		46	2	276		28	92	18
United Kingdom 1992 (new plants)		46	2	276		46 (92)	92	18
Belgium 1991		46	2		92	28	92	18
Netherlands 1989		9	1	37	65	5	46	9
Sweden 1986		80	1	190	320	17	80	
Norway 1992		110		330		11	110	
Switzerland 1991		18	2	46	74	9	46	18
Austria 1989		9	1	46	92	14	46	18
Germany 1990	mean 24 hour	9	1	46	184	9	46	9
Germany 1990	1/2 hour max	55	4	183	366	55	92	35
Denmark 1991	mean 24 hour	60	2	276		37	92	18
U.S.A. NSPS 1995	New Facilities	27 (95%)**		56 (80%)	197 (daily)	17	various	
Existing Facilities	>35 tpd & <225 tpd	261 (50%)		147 (50%)	exempt	49		
	>225 tpd	33 (95%)		58 (95%)	263-329	19		
Canada CCME Guidelines 1989		75 (90%)				20	57/114	
Alberta 1983		110		470				
British Columbia 1991		70	3	250	350	20	55	40
Ontario Guideline A-7 1995		27		55	207	17	permit specific	permit specific
Japan 1984		778			570	89	69	

Note: 1. ** where percentage values are provide in bracket following the emission level they refer to a minimum removal efficiency required by the jurisdiction In most cases these conditions are enforced as the lesser of the two conditions either 7 mg/m^3 or 95% removal so that if 95% corresponds to 10 mg/m^3 it would be judged satisfactory performance as would 7 mg/m^3 with only 90% removal.

2. Various refers to levels for different types of systems as outlined in Table 5.2.

5.2.2 Emissions of Combustion Products and Acid Gases

The conventional by-products of combustion from most fuels include, water vapour, carbon dioxide, sulphur dioxide, oxides of nitrogen, particulate matter, carbon monoxide and hydrocarbons. Since MSW contains chlorinated plastics and other materials which may contain low but measurable concentrations of chlorine, such as wood, plant and vegetable matter and related products (e.g., paper products), hydrogen chloride is another by-product of combustion. Other constituents of MSW can contain fluorides and bromides which give rise to other halogenated gases.

Reviewing the standards by compounds, it is evident that most jurisdictions place limits on HCl and dust (particulate matter) from MSW incinerators. Carbon monoxide, sulphur dioxide and oxides of nitrogen standards are the next group of frequently regulated substances with only a few jurisdictions regulating hydrogen fluoride and total hydrocarbons (expressed as an equivalent amount of methane, CH_4 or as elemental carbon).

Hydrogen Chloride
HCl standards are expressed as either removal efficiency requirements or emission limits. A removal efficiency of 90% is required in most jurisdictions using this approach. However, U.S. regulation require 95% if the concentration exceeds 27 mg/Rm^3 @ 11% O_2. Promulgated emission limits differ in both averaging time and concentration. The lowest values are 24-hour averages of 9 mg/Rm^3 in the Netherlands and Germany. The U.S. value of 27 mg/Rm^3 represents the average of three, one-hour test results, or a three-hour average. Continuous emission monitoring [CEM] for HCl can be required in Germany and some Canadian jurisdictions. In Ontario those facilities with CEM systems operate with 24 hour average emission limits equal to the standard.

Particulate Matter
Until the late 1980s, the emission requirements for particulate matter were decreasing to the 20 - 30 mg/Rm^3 @ 11% O_2 range, based on the results of standard sampling methods that provide a 2 to 4 hour composite sample. More recently, North American standards have dropped to the lower end of this range, whereas European standards are now half this concentration. The newer standards reflect test data and the development of newer APC systems which are capable of consistently limiting particulate emissions to lower levels.

Sulphur Dioxide
Sulphur dioxide (SO_2) standards range widely from 300 mg/Rm^3 @ 11% O_2 to the newer European standards of 37 to 46 mg/Rm^3. The lower range reflects the increased application of more complex APC systems. The U.S. national standard for new facilities contains a removal standard of 80% if emissions exceed 55 mg/Rm^3 @ 11% O_2, but

some states have set higher performance targets. For example, the Commerce facility in California is licensed for 30 mg/Rm^3 @ 11% O_2 based on a 24-hour average.

Oxides of Nitrogen

Most MSW incinerators generate NO_x emissions in the 300 to 450 mg/Rm^3 range, thus emission controls are required if the facility is to operate at regulated levels ranging from 65 to 190 mg/Rm^3 @ 11% O_2. NO_x control systems are capable of meeting the 70 mg/Rm^3 @ 11% O_2 level required by some European regulations. To avoid problems inherent with operations at this level, namely "ammonia slip" and visible plumes, increased efforts are being placed on monitoring residual ammonia levels after the NO_x control section and adjusting ammonia flow to reduce the slip.

Carbon Monoxide

Carbon monoxide levels were discussed in the previous section. Generally, well operated modular facilities will be operated at 4-hour average levels lower than 40 mg/Rm^3, whereas some incinerator variants may record 200 mg/Rm^3 values due to quenching of smouldering char or limitations in air distribution. Different jurisdictions use different averaging times for CO limits, but all appear to produce fairly consistent standards in the 50 to 100 mg/Rm^3 range.

Total Hydrocarbons

The total hydrocarbon [THC] standard is also related to combustion performance since higher CO values are normally accompanied by higher THC values. The standards range from 10 to 40 mg/Rm^3. Furnace operations must be adjusted to minimise this indicator since few back end control strategies effectively reduce these emissions. Auxiliary burners have resulted in higher THC emissions at some facilities since they do not perform as efficiently as the furnace does when burning waste.

Hydrogen Fluoride

In recent years, more jurisdictions have developed specific hydrogen fluoride (HF) standards for incinerators. Earlier, non-specific regulations, such as the U.S. EPA Prevention of Significant Deterioration (PSD) standards and the U.S. National Emissions Standards for Hazardous Air Pollutants (NESHAPS) provisions, limited general HF releases. Incinerators equipped to control acid gases generally meet these absolute standards. Of those jurisdictions with specific standards, the majority are in the range of 1 to 4 mg/Rm^3 @ 11% O_2 and the average is 2 mg/Rm^3 @ 11% O_2.

5.2.3 Trace Metals Emission Standards

Generally, although it is possible to set absolute numbers for emission levels of most individual contaminants, the task is much more difficult when the synergistic effects of

combinations of contaminants are considered. In the case of individual species, scientists and regulators determine the level at which effects are observed in sensitive receptors (i.e., microbes, invertebrates, higher aquatic organisms, vegetation or mammals) and then use this information to set maximum chronic or acute exposure levels. Conversely, synergistic effects can only be examined within a finite set of combinations. Table 5.5 provides a summary of trace metal emissions limits. The metals in the classes vary by country as shown in the note below the table.

Table 5.5
Municipal Solid Waste Incinerator Emissions Limits - Trace Metals
(Values expressed as mg/Rm^3 @ 11% O_2)

Jurisdiction (Country/State/Province)	Trace Metals by Category		
	I	II	III
European Economic Community 1991	0.20**	1.0	5.0
Italy	0.11		3.2
France 1991	0.05*	0.05*	5.0
Netherlands 1993	0.05**	††	5.0
Sweden 1986 (Recommended)†	0.08		
Switzerland 1986	0.22	1.0	5.4
Germany 1990	0.05 Hg, 0.05 Cd + Tl	0.5***	NA
Denmark 1991	0.20	1.0	5.0
Austria	0.1 Hg, 0.05 Cd	2.0 Pb+Zn+Cr	0.5 As+Ni+Cu
United Kingdom	0.1*	1.0****	NA
U.S.A. 1995 MACT Rule (NSPS) New >35 tpd	0.014 Cd	0.14 Pb	0.056 Hg
Existing >35 & <225 tpd	0.07 Cd	1.12 Pb	0.056 Hg
>225 tpd	0.028 Cd	0.34 Pb	0.056 Hg
Canada CCME Guidelines 1988	none	none	none
British Columbia 1991	0.2 Hg/0.1 Cd	0.004 As/0.001 Cr	0.05 Pb
Burnaby permit 1983	0.2	1.0	5.0
Ontario Guideline A-7 1995	0.014 Cd	0.14 Pb	0.057 Hg

Note: Generally, Hg and Cd are in Class I but Sweden has Hg only and the old German and British Columbia standards include Tl in Class I.
Class II has As and Ni in the EC;
Class III for the EC is Pb, Cr, Mn and Cu; in the Netherlands & Switzerland Pb and Zn; elsewhere the class contains Pb and Cr.

* the French regulations adopted the EC Directive but tightened the cadmium and mercury emission levels.

** represents total for each compound Hg and Cd.

*** the German standard combines As, Co, Cr, Ni, V, Sn, Sb, Pb, Cu, and Mn.

**** the U.K. standard combines As, Cr, Ni, Sn, Pb, Cu, and Mn.

NA no standards for Category III.

† Individual for each plant.

†† Total of Pb, Sb, Cr, Cu, Mn, V, Sn, As, Co, Ni, Se, Te should not exceed 1.0 mg/Nm^3 (max hourly average)

The regulation of trace metal emissions from incinerators is a new development in North America. The U.S. NSPS (1995) regulations are based upon the Maximum Achievable Control Technology, i.e., those demonstrated by the five best plants in operation, [MACT] criteria and these values have been adopted by the province of Ontario, Canada. Previously, Ontario had applied the Point of Impingement dispersion calculation procedure to determine acceptable stack emissions. The province of British Columbia adopted the TA Luft (1986) values in setting permit conditions for the Burnaby facility. Previously, in the U.S., NESHAP standards exist for lead, mercury and beryllium, along with PSD limits for lead with some state and local standards also existing (Jordan, 1987).

5.2.4 Trace Organic Emission Standards

Standards for organics are listed on Table 5.6. These are more difficult to develop than inorganic standards because there are differences in toxicity within a family of organic compounds. For example, there are 210 congeners of polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) divided into eight homologues for each compound. Since each congener has a wide range of toxicity, scientists developed a scaling factor (the Toxic Equivalency Factor, TEF) for the 17 congeners that are considered to be the most toxic. A Toxic Equivalent (TE) value is then calculated by:

$$TE = \sum_{i=1,n} (X_i \times TEF_i)$$

where X_i = concentration of a specific congener; and,
TEF_i = the toxic equivalency factor for that congener.

This cumulative value can then be used to estimate the potential total toxicity relative to a single congener, namely 2,3,7,8-TCDD, which is considered the most toxic congener of the PCDD/PCDF group. The most common scheme for applying PCDD/PCDF toxicity factors is shown in Table 5.7. Not all legislation has adopted the ITEQ approach. The Eadon equivalency factors used in some European legislation result in a value that is approximately twice the ITEQ value for the same sample. This implies that a value of 0.1 Eadon is equivalent to 0.05 ITEQ. With that in mind, the Danish value is close to the CCME Canadian level. Furthermore, while not considered particularly significant, there are subtle difference in the sampling and analytical methods used for these compounds in Europe and strict comparisons to North American numbers may lead to invalid conclusions. The German value results from measurements expressed on a wet basis and for a considerably longer averaging time than that conventionally used in North America. The net effect of this is that the German value equates to approximately 0.3 ng ITEQ/Rm^3 @ 11% oxygen. On the basis of toxic equivalents, the Swedish standard would appear to be the lowest at 0.05 ng/Rm^3.

Table 5.6
Municipal Solid Waste Incinerator PCDD/PCDF Emissions Limits

Jurisdiction (Country/State/Province)		PCDD/PCDF (ng/Rm^3) (Toxic Equivalents)
Netherlands 1993		0.1
Sweden 1986 (Recommended)		0.1 Eadon
Germany 1990		0.1
U.S.A. 1995	New >35 tpd	9 (total)
	Existing >35 & <225 tpd	88 (total)
	>225 tpd	21 (total) except ESP equipped facilities 42 (total)
Canada CCME Guidelines 1988		0.5
British Columbia 1991		0.5
Ontario Guideline A-7 1995		0.14
Japan 1990		0.55

Table 5.7
Toxicity Equivalency Factors (TEFs) for Specific PCDD and PCDF Congeners

Homologue	Positions Chlorinated	Equivalency Factor
Dioxins		
TCDD	2,3,7,8	1
PeCDD	1,2,3,7,8	0.5
HxCDD	1,2,3,4,7,8	0.1
	1,2,3,6,7,8	0.1
	1,2,3,7,8,9	0.1
HpCDD	1,2,3,4,6,7,8	0.01
OCDD	1,2,3,4,6,7,8,9	0.001
Furans		
TCDF	2,3,7,8	0.1
PeCDF	1,2,3,7,8	0.01
	2,3,4,7,8	0.5
HxCDF	1,2,3,4,7,8	0.1
	1,2,3,7,8,9	0.1
	1,2,3,6,7,8	0.1
	2,3,4,6,7,8	0.1
HpCDF	1,2,3,4,6,7,8	0.01
	1,2,3,4,7,8,9	0.01
OCDF	1,2,3,4,6,7,8,9	0.001

Note: * When only homologue test data are available, then the most conservative (largest) equivalency factor should be applied.

NATO CCMS, 1988

The U.S. EPA 1995 standard for PCDD/F does not involve the use of toxic equivalents; rather compliance with the standard specified must be determined through the use of a specific sampling and analytical method that quantifies the amount of each of the 2,3,7,8 substituted congeners (isomers). These are totalled and the total is compared to the standard. This effectively uses the same congeners that are included in the ITEQ scheme, but applies no weighting to the various levels of these material.

5.3 CURRENT ASH AND RESIDUE DISPOSAL PRACTICES

The bulk of the residue generated at an MSW incinerator consists of grate ash. In Canada, most European countries and Japan, bottom ash is handled separately from the other residue streams, whereas the current trend in the United States is to combine all the residue streams and dispose of this material in dedicated landfills. In most jurisdictions, bottom ash is disposed by landfilling and regulations governing this activity have been developed. However, utilisation of the material as a substitute lightweight aggregate has emerged as a viable option to landfill disposal and experience has led to various regulations being developed specifically for utilisation practices. Since the regulations and management practices for ash are evolving in all countries, the current trends and approaches are described below.

5.3.1 Disposal of Bottom Ash

Canada

In Canada, ash is currently handled as two separate streams, bottom ash and fly ash/APC residue. The CCME guidelines (1989) recommended ash be handled in this manner to prevent contamination of the bulk of the material by the high trace metals concentrations in the fly ash. Furthermore, the guidelines suggested that bottom ash could be disposed in a conventional municipal landfill, which is the current procedure in British Columbia, Ontario and Quebec, although the bottom ash from the Burnaby, B.C., facility is used for road construction purposes within a landfill.

Denmark

Since 1984, Denmark has utilised a very large portion of the bottom ash generated at its incineration facilities. In 1993/94, Denmark utilised between 400,000 to 450,000 tonnes of processed bottom ash which represents almost 100% of the total amount generated (Hjelmar, 1994). The ash is processed by screening and removal of ferrous materials to generate an upgraded product. Previously, approximately 26% of the total amount produced was disposed in dedicated monofills. The term monofill refers to segregation of ash from other waste materials, including MSW. A further 36% was used for fill or land reclamation purposes (Ludvigsen, 1991). The impetus for wide spread use of ash stems from the imposition of a State tax on disposal which was initiated in 1987 (Hjelmar and Ludvigsen, 1993).

France
France has a landfill regulation (Law on Waste Disposal, 1975, revised 1992) which suggests that landfilling is the last resort after all recyclable uses have been made of the material. This encourages incineration of waste after recycling and utilisation of residues where appropriate. Any material landfilled must contain less than 5% organic matter and the TOC of the leachate is limited. The act stipulates categories of materials according to its solubility. A material can be recycled if the solubility is less than 3%. There are two classes of landfills: Class 1, Hazardous Waste with a solubility greater than 5% and less than 10%; and Class 2 where the material has a solubility less than 5%. All landfills must be lined.

Bottom ash is the only material that is currently considered appropriate for re-use, however, given the limits on recycled materials, most residues will require some treatment before they can be used or they will require disposal.

Germany and Switzerland
In Germany and Switzerland, landfill disposal of materials requires that the residues meet a loss on ignition criteria (a measure of the unburned material in the ash) of less than 10% and contain less than 10% soluble salts. Furthermore, leachate from the residue must meet criteria for various trace metals based on elution with distilled water.

In 1993, the German Bundesministerium für Umwelt issued a new directive on landfills used for both MSW and incinerator residue disposal. This legislation defines two classes of landfills based on the total organic carbon, loss on ignition at 550°C, leachate quality as defined by DEV S4, and solubility. The new directive promotes utilisation as the preferred option for bottom ash. If there are no available markets for utilisation, disposal should be at a Type 1 landfill. After simple in-plant treatment, bottom ashes from properly operated incinerators will be able to meet the criteria (Schneider et al., 1994). These are summarised in Table 5.8. The objective of these standards is to reduce the reactivity of materials being placed in landfills.

Netherlands
In the Netherlands, the Soil Protection Act of 1987 provides statutory authority for protection of the environment through limiting the pollution of soil by anthropogenic activities. Under the act, construction materials are regulated to prevent contamination from industrial residues that may be used in construction. The regulations limit releases to the environment to a small percentage of the existing level of that contaminant in the first metre of underlying soil. The effect of these regulations is to emphasise the efforts of controlling releases of contaminants found in very low concentrations in the Dutch environment. This is a distinct difference from many other jurisdictions where release

Table 5.8
Summary of German Landfill Requirements

Classification Criteria For Landfills	Standard Not To Be Exceeded	
	Type 1	Type 2
TOC (%)	1*	3**
LOI (%)	3*	5**
pH	5.5 - 13	5.5 - 13
Conductivity (uS/cm)	10,000	50,000
TOC (eluate, mg/L)	20	100
Phenols	0.2	50
Solubility (%)	3	6
Leachate Quality (mg/L) (from DEV S4 Procedure)		
As	0.2	0.5
Cu	1	5
Hg	0.005	0.02
Zn	2	5
Cd	0.05	0.1
Cr^{+6}	0.05	0.1
Ni	0.2	1.0
F	5	25
Pb	0.2	1
NH_4	4	200
CN	0.1	0.5
AOX	0.3	1.5

* = for new incinerators ** = for old incinerators

TA Siedlungsabfall, 1993

limits are based largely on the toxicity of the contaminants. Under the Soil Protection Act, a separate regulation deals with the disposal of wastes (Regulation for Disposal). In the Netherlands, a large portion (>80%) of the bottom ash produced is utilised in embankment and roadbase applications. Ferrous rejects are recycled.

Sweden

It is estimated that Sweden produces 400,000 tonnes of bottom ash and 60,000 tonnes of fly ash and APC residues annually (Fällman and Hartlén, 1992). This quantity fills 250,000 m^3 of dedicated monofill space in recently approved disposal sites. Each site has its own permit requirements which were approved by the Environmental Franchise Board. Furthermore, monofills that are used for both bottom ash and APC residues must dispose of these streams in separate cells. Current recommendations suggest that leachate be collected for the initial filling period and after this time infiltration should be kept below 50 mm/year by the use of proper soil covers. The Swedish regulators are currently monitoring disposal requirements developing in the rest of Europe with a view to amending their standards. Regardless of the standards imposed, local citizens are afforded an opportunity to review and comment on any landfill development plans during the approval stages. Efforts to develop a suggested re-use criteria are also under way in Sweden as discussed in the next section.

United Kingdom

In the United Kingdom, no special provisions exist for the disposal of ash from MSW incinerators, although the issue is under review. All ash generated in society, be it from residential, commercial or industrial establishments, is classified as a "controlled waste". Controlled waste must be disposed at approved licensed facilities that can handle the material. Licensing requirements reflect the need to preserve the environment and ensure neither the water resources nor public health are endangered by the disposal practice. The current practice is to co-dispose with MSW or to use the material as cover in older landfill sites. These sites are under reducing conditions and the theory is that they present a more stable environment for the containment of trace metals. The regulations governing ash disposal are expected to change when the new Air Emissions Regulations force facilities to install new APC systems in 1996.

United States

Up until the mid 1980s, most MSW incineration residues in the U.S. were disposed in co-disposal situations with MSW. Regulations for disposal varied by state and local situation, and considerable debate and confusion existed about the status of these materials with respect to the RCRA Subtitle C (hazardous waste) testing and management requirements. This was brought about by an exemption for "household waste" from the provisions of Subtitle C. However, in the Spring of 1994, the U.S. Supreme Court ruled that MSW incinerator ash was no longer exempt from testing using the Toxicity Characteristic Leaching Procedure (TCLP). Thus ash (combined or

separated bottom ash and APC residues) which passes the criteria associated with the TCLP can be landfilled or monofilled, however, ash which fails the criteria must be disposed as a hazardous waste. This involves disposal in a secure landfill with provisions including a series of liners and leachate collection and treatment facilities which are more stringent than the design criteria for Subtitle C landfills.

Most new facilities are using monofills for combined residue disposal, but where space is limited, interest in utilisation is increasing. Although the majority of the facilities combine the residue streams, a small number segregate the bottom and fly ash/APC residue streams to facilitate treatment of the fly ash/APC residue. Furthermore, regulations regarding ash management still vary widely from State to State. For example, New York State requires semi-annual testing for ash and are developing a procedure to handle this material as a special waste (e.g., Bill 10780, State of New York), whereas the State of Florida has permitted the use of ash in artificial marine reef construction projects. Moreover, although some States actively discourage the practice of co-disposal with MSW, other States endorse the practice.

Japan
In Japan, the Waste Disposal and Public Cleaning Law, which addresses all aspects of waste disposal, was thoroughly amended in 1991. Under that law, incinerated ash is classified as either bottom ash or fly ash. Bottom ash is treated as normal domestic waste and disposed directly into sanitary landfill sites.

5.3.2 Disposal of Fly Ash and APC Residues

The options for handling and disposing of the finer ash streams from incinerators are more limited. Most jurisdictions treat the material as a hazardous waste.

Canada
In Canada, the fine ash material must be handled as a hazardous waste. The disposal options include transfer to a hazardous waste disposal facility or treatment of the residues prior to disposal. Various treatment alternatives from disposal in secure landfills to solidification are being evaluated, but there are few regulations in place to evaluate the efficacy of a treatment process. The exception is in British Columbia, where the treated ash must pass a battery of laboratory tests prior to disposal in a conventional landfill. The testing protocol includes evaluating the treated residue using chemical, engineering, durability and leaching tests (Government of British Columbia, 1992).

Denmark & the Netherlands
In Denmark, APC residues from the dry or semi-dry processes and fly ash are currently classified as hazardous wastes and are disposed in dedicated monofills with leachate

collection systems and bottom liners, and often with impermeable cover layers. Wet scrubber sludges are generally monofilled alone or are mixed with fly ash residues. All of these measures are only considered temporary solutions until suitable treatment systems are made available.

At sites in Denmark and the Netherlands, APC residues are stored in polyethylene bags in landfills that have leachate collection systems and bottom liners. Generally, APC residues in the Netherlands are sent to a hazardous waste landfill site, although nearly 40% of the ESP residues from Dutch facilities are currently utilised as a very small percentage filler in asphaltic concrete mixes, but this practice is waning. This residue stream is segregated from all other streams for this purpose.

France

The 1991 French law on MSW incineration adopted the EEC directive on air emissions but has tighter mercury and cadmium standards. This has resulted in an increased use of wet APC systems, and hence, more sludge from these systems. The changes in regulations have fostered increased study into ways of modifying residues to meet the disposal criteria mentioned above. Immobilisation of contaminants by solidifying with hydraulic binders is being practised in some areas, and four organisations are currently exploring vitrification alternatives. One manufacturer is utilising the wet scrubber system to modify the residue to meet the criteria (Knoche, 1992).

Germany

In Germany, the APC system has to be designed in a way to minimise the production of harmful residues (Bundesministerium, 1993). Heat recovery system ash is separated from dry/semi-dry scrubber residues in some facilities. The fly ash and APC residues are classified as a hazardous waste and requires disposal in either approved landfills or preferably in underground disposal sites such ash old salt mines or in special cells of municipal waste disposal sites. Mühlenweg (1990) estimates that 5% of the total fly ash/APC residue stream (210,000-240,000 tonnes/year) is deposited in underground sites, less than 1% is re-used and the balance goes to surface storage. To minimise the release of dust from surface stored materials, it is packaged in large bags or moistened. German regulations allow boiler/economiser and filter ashes to be modified to reduce the need for controlled disposal, however, few methods have been developed to the commercial scale.

Heat recovery and filter ashes along with APC residues contain high quantities of water soluble salts and in Germany they are required to be disposed of in hazardous waste landfills. Limited work has been done to explore the options for treatment/re-use of these materials, but these processes have not progressed beyond pilot scale (Juritsch, 1990; Kurzinger, 1990).

Netherlands
At the present time, APC residues and fly ash are considered hazardous wastes and are generally managed in a similar manner to that used in Denmark.

Sweden
In Sweden, APC residues are disposed separately from bottom ash. The Environmental Franchise Board is responsible for setting the requirements for these disposal sites. It has been found that the Swedish infiltration limit of 50mm/year is not suitable for limiting releases from APC residues and fly ash. A new practice is to stabilise these materials before disposal. This is done at one facility in Stockholm by adding 40% low calcium cement to the residue stream. This increases the volume of the stream but further retards the infiltration rate into the material. Other options for the disposal of APC residues and fly ash are currently being examined, including slurry deposition to achieve better compaction, advanced immediate compaction to reduce permeability and the use of plastic covers during deposition to reduce infiltration.

Japan
In Japan, fly ash and APC residues are treated as a domestic waste under special control. Before disposal, they have to be tested via a leaching procedure and compared to waste disposal standards. In order to treat fly ash, the Ministry of Health and Welfare specified four treatments:

- Melting and solidification
- Solidification by cement
- Stabilisation using chemical agents
- Extraction with acid or other solvent

After all standards have been passed, the treated fly ash could be disposed directly into sanitary landfill sites with other domestic wastes.

5.3.3 Utilisation

Two fundamental concerns with utilisation applications are that 1) the physical properties of the material are appropriate for the intended application (i.e., bearing capacity, compaction, etc.), and 2) the application does not lead to environmental degradation. The latter situation relates mainly to the leaching of metals and salts from the ash, since the potential loading of ash within a fill application may pose a potential problem. In Europe, the materials are used as a civil engineering material, largely as base and sub-base for roadways. Each country has considered the environmental implications of these uses and developed guidelines for implementation. While the subject of utilisation is discussed in more detail later in the document, a brief discussion of existing regulations governing the use of residues is included here.

Canada

As mentioned previously, although no major efforts have been devoted to utilisation in Canada, the Greater Vancouver Regional District has evaluated bottom ash for utilisation applications, and currently uses the material for construction of roadways within a landfill site. The bottom ash undergoes ferrous removal prior to leaving the Burnaby facility, but no other processing is done other than compaction during placement.

One of the major impediments to bottom ash utilisation is that there has been little economic incentive to divert materials from landfill. Should sufficient regulatory criteria be put in place to allow the use of bottom ash as a lightweight aggregate, it is likely that the practice would be considered for ash from some of the major facilities.

Denmark

Although part of the bottom ash stream from incinerator facilities in Denmark has been used in sub-bases for roads, bicycle paths and parking lots since 1974, the first Danish utilisation requirements were not developed until 1983 (Statutory Order No. 568 of Dec. 6, 1983). Moreover, these requirements only applied to the use of small to moderate amounts of ash. Large scale applications (>30,000 tonnes or 5 m thickness) are regulated under the Environmental Protection Act (Disposal and Discharge Permit section). Additional guidelines for road sub-bases were developed in 1989 by the Danish Highway Department (Pihl et al., 1989 in Hjelmar, 1990). The Statutory Order is currently being reviewed. Ferrous material is removed from the ash by screening and then magnetic separation to generate an upgraded material for recycling purposes. The portion of the bottom ash stream which cannot be used is disposed in dedicated monofills.

A Danish testing protocol has been developed to determine the suitability of ash for utilisation based on chemical parameters (Hjelmar, 1990). The conditions include a pH >9 for a 1% slurry of the material, alkalinity of >1.5 eqv/kg, metals levels as determined from a HNO_3 leach of Pb <3000 ppm, Cd<10 ppm and Hg<0.5 ppm. There are also restrictions on the placement of ash that passes the criteria. Under paved roads, the maximum average thickness allowed is one metre and the ash must be above the highest groundwater table and more than 20 metres from the nearest well. Under unpaved roads the same regulations apply except the thickness is restricted to 0.3 m. Sub-base material has specific size requirements (<45 mm with a specified fines level), must have been stored for at least one month, have a loss on ignition of <10% and a water content between 17 and 25%.

France

France currently utilises 45% of the bottom ash in roadbeds, however, this may change due to recently introduced regulations (Ministere de l'Environnment, 1994). Bottom ash destined for a utilisation application must meet criteria in relation to combustible content

and leaching characteristics. The LOI content must not exceed <5% and the results from the leaching test AFNOR NF X 31-210 are compared to the list given in Table 5.9 The material will still require ferrous removal, screening and aging.

Table 5.9
Requirements for Bottom Ash Utilisation - Leaching (mg/kg unless noted)

Total Soluble Solids	As	Cd	Cr^{+6}	Pb	Hg	SO_4	TOC
< 5%	< 2	< 1	< 1.5	< 10	< 0.2	< 1.0%	< 1500

Netherlands
The utilisation of ash in building materials is governed under the Soil Protection Act in the Netherlands. This regulation covers both granular (aggregate) and monolithic (solids >50 cm^3 in size) and classifies materials according to chemical composition and leaching characteristics. If the material does not meet the requirements of one of the categories it cannot be placed in contact with the soil. Generally, material containing MSW incinerator ash of any form can be used if it meets the requirements but must be reclaimed after its useful life is over. Bottom ash must be placed at least 70 cm above the groundwater table and should be isolated from infiltration. Leaching requirements for material are relaxed for placement in the marine environment so that Cl, F and SO_4 leaching levels can be higher. The Dutch leaching limits are derived on the basis of a 1% increase in the average natural soil composition for the one meter of soil under the construction after exposure of 100 years.

A process of certifying MSW incinerator residues for utilisation is currently being developed in the Netherlands. Other work has been ongoing to develop technical specifications for the use of bottom ash in roadway construction.

Germany
In Germany, the data on the reuse of bottom ash is not consistent, but they indicate a substantial amount is used in construction applications. A 1991 survey of the 48 German incinerator facilities indicated that the production of bottom ashes was approximately 2,400,000 tonnes, 60% of which (or 1,450,000 tonnes) were utilised (Krasse & Radenberg, 1994). Some large scale projects, each using tens of thousands of tonnes of material, were initiated during the late 1980's to demonstrate the capability of bottom ash use in road bases, embankments and noise protection walls (Toussaint, 1989).

In March 1994, the federal states passed new legislation regarding ash management (LAGA, 1994). The legislation is intended to promote the reuse of as many residue streams as possible, but the main emphasis is on bottom ash. Bottom ash destined for reuse cannot contain heat recovery or fly ash and the ash requires pretreatment to

remove the metallic and unburnt materials from the mineral fraction. The recyclable ferrous scrap must contain >92% Fe with a grain size between 50-70 mm, with no less than 5% being under 5 mm in size.

Aging has been found to increase the chemical stability of the ash by washing out readily leachable salts, forming carbonates via the sorption of CO_2, and hydrating metallic and oxide forms of elements like aluminum. Aging also allows swelling reactions to occur prior to placement. The ash must be screened to remove material > 45 mm, which is then returned to the incinerator, and the remainder is aged for three months before qualifying for testing to determine its suitability for use. The tests involve an assessment of the loss on ignition (must be less than 2%), water soluble salt levels (less than 1%) and the generated leachate (for various ions and metals). At least one sample > 2 kilograms in weight is required per 10 m^3 of ash, and there must be a least 10 grab samples per pile of ash.

In addition to bottom ash, there are criteria in place for the use of by-products from APC systems, namely, NaCl, Na_2SO_4, gypsum and HCl. The criteria are given in Tables 5.10 - 5.13.

Sweden

In Sweden, it has been suggested that the effect of bottom ash utilisation should be quantified in absolute terms and compared to the effects of using natural alternatives (Hartlén and Lundgren, 1991). Consequently, a set of utilisation regulations is being developed based on a scheme to classify materials into at least three classes: inert, usable with restrictions, and unusable and requiring disposal. While Sweden has not utilised much bottom ash to date, the proposed guidelines are similar to those outlined above:

- pre-screen and remove ferrous
- maximum grain size 50 mm
- no more than 10% smaller than 0.06 mm
- loss on ignition less than 5% and age for three months.

Hartlén and Lundgren (1991) also suggest that aged ash should contain approximately 17% water, a condition they consider acceptable since it allows compaction with a 10 tonne vibrating roller to a 90% modified proctor. In addition, they suggest that after grading, 70% of the material is a suitable substitute for coarse aggregate. One-third of the rejects are coarse scrap that can be sold for recycling, whereas the rest must be disposed. The largest market for processed bottom ash is as a substitute aggregate.

Limits are also proposed for metals in leachates (Hartlén and Lundgren, 1991). The material can be used in embankments, under bicycle paths and low traffic roads, and under light buildings and floor structures. The thickness of the fill is generally restricted to a maximum of 3 metres. Furthermore, it must be placed above the groundwater table and below pavement.

Table 5.10
German Specifications for NaCl Production from APC Systems (µg/g)

Parameter	Limit	Parameter	Limit
NaCl	> 95-96%	Cu	5
Ca	2%	Mo	1*
Mg	0.2%	V	1*
SO_4	2%	Ti	10
K	1500	Zn	1
F	60	Cd	1*
Br	50	Hg	1
I	10	Si	***
Sr	20	Sn	1**
Ba	20	Pb	1**
Fe	10	As	0.5
Mn	1*	Al	1000
Ni	1*	N	20
Co	1*	TOC	****
Cr	1*		

* = critical value ** = less critical *** = not critical **** = to be determined

Table 5.11
German Specifications for Na_2SO_4 Production from APC Systems

Parameter	Limit	Parameter	Limit (µg/g)
Na_2SO_4	> 41.5%	Fe	50
Cl	1%	Zn	250
H_2SO_4	1%	Mn	2
pH	Neutral	V	10
Insoluble fraction	0.05%	Al	10
Water Content	60%	Sr	10
Colour	White	Cr	10
By-products	None	Mg	25
COD	100 mg O_2/L	Ca	50

Table 5.12
German Specifications for Gypsum Production from APC Systems

PARAMETER	LIMIT
Moisture Content	10%
$CaSO_4 \cdot H_2O$	> 95%
pH	5 - 9
Colour	> 80% White
Odour	None
Mean Grain Size	> 60% passing 32 µm
By-products	5%
Soluble (water) MgO	0.1%
Soluble Na_2O	0.06%
Soluble K_2O	0.06%
Soluble Cl	100 µg/g
Soluble SO_2	0.25%
$CaSO_3 \cdot ½H_2O$	0.5%
Al_2O_3	0.3%
Fe_2O_3	0.15%
SiO_2	2.5%
$CaCO_3 + MgCO_3$	1.5%
NH_3, NO_3	none
TOC	0.1%
Trace Elements	Non-toxic concentrations, nonradioactive

Table 5.13
German Specifications for HCL Production from APC Systems (mg/L)

Parameter	Limit	Parameter	Limit
HCl	30 - 31%	HBr	25
SO_4	20	HI	10
Heavy Metals	1 Total	HF	10
Fe	10	NO^{3-}	10
Cd	0.1	NH^{4+}	1
Hg	0.1	TOC	5
As	0.1	AOX	1
Tl	0.1	PCDD/PCDF	1 ng I-TE/L
Cl_2	10		

Japan

Almost all the incinerated ash and APC residue in Japan (5,991,000 tonnes in 1991) are disposed in sanitary landfill sites. This value accounts for 35.6% of the 16,800,000 tonnes of landfilled material in 1991. A process of melting MSW incinerated slag is currently being developed and applied on a commercial scale. The Japan Waste Research Foundation pilot project is intended to determine the effectiveness of this melted slag as an additive to asphalt and as an upper and lower road bed material. Preliminary results indicate no appreciable difference in holding strength or road condition was found between the experimental slag and natural materials (Ando, 1993).

United States

Various utilisation alternatives have been investigated in the United States. Long Island Regional Planning Board (1990) reported that ash characterisation studies were sponsored by U.S. government agencies as early as the 1960s. These continued into the mid-1970s with particular emphasis on aggregate substitution in portland cement and asphalt paving (Kenahan et al., 1966; West Virginia University, 1971; Haynes and Ledbetter, 1975; Pavlovich et al., 1977; Pindzola, 1976; and Collins et al., 1977). The recommendations from these studies included limiting combustibles to less than 10% and storing materials for several months prior to use to reduce moisture and residual organic concentrations. The Long Island RPB (1990) report also refers to other studies in the United States where incinerator ash has been used for various aggregate purposes and suggests that the more current data show better performance. The report attributes this to improved combustion efficiency and less organic material in the ash. The authors note that the major difference between ash utilisation in the U.S. and Europe is the fact that, in the U.S., the emphasis has been on ash in a combined matrix such as concrete or bituminous products.

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