2.3 Medical Waste Incineration

Medical waste incineration involves the burning of wastes produced by hospitals, veterinary facilities, and medical research facilities. These wastes include both infectious ("red bag") medical wastes as well as non-infectious, general housekeeping wastes. The emission factors presented here represent emissions when both types of these wastes are combusted rather than just infectious wastes.

Three main types of incinerators are used: controlled air, excess air, and rotary kiln. Of the incinerators identified in this study, the majority (>95 percent) are controlled air units. A small percentage (<2 percent) are excess air. Less than 1 percent were identified as rotary kiln. The rotary kiln units tend to be larger, and typically are equipped with air pollution control devices. Approximately 2 percent of the total population identified in this study were found to be equipped with air pollution control devices.

2.3.1 Process Description[1-6]

Types of incineration described in this section include:

- Controlled air,

- Excess air, and

- Rotary kiln.

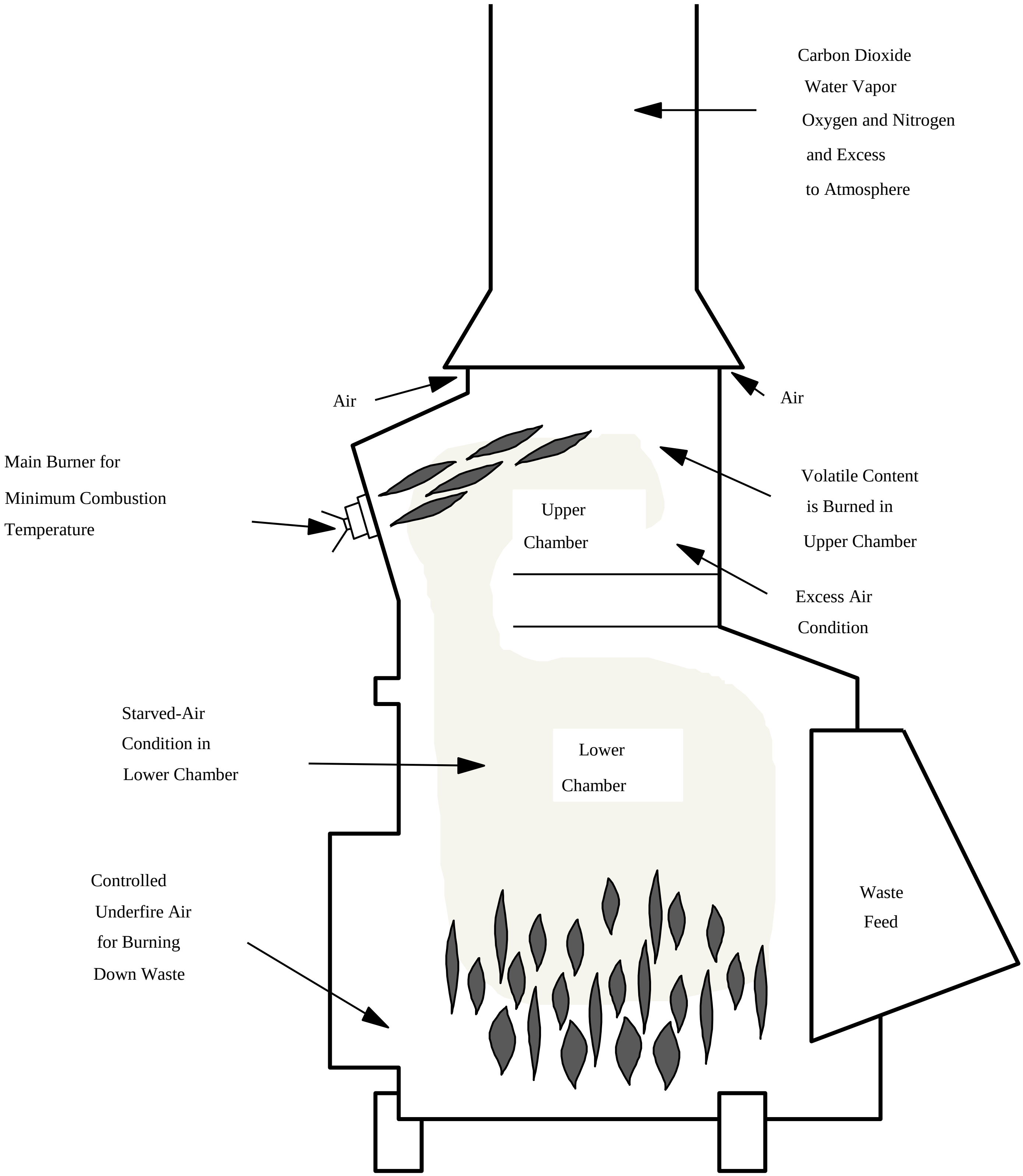
2.3.1.1 Controlled-Air Incinerators -

Controlled-air incineration is the most widely used medical waste incinerator (MWI) technology, and now dominates the market for new systems at hospitals and similar medical facilities. This technology is also known as starved-air incineration, two-stage incineration, or modular combustion. Figure 2.3-1 presents a typical schematic diagram of a controlled air unit.

Combustion of waste in controlled air incinerators occurs in two stages. In the first stage, waste is fed into the primary, or lower, combustion chamber, which is operated with less than the stoichiometric amount of air required for combustion. Combustion air enters the primary chamber from beneath the incinerator hearth (below the burning bed of waste). This air is called primary or underfire air. In the primary (starved-air) chamber, the low air-to-fuel ratio dries and facilitates volatilization of the waste, and most of the residual carbon in the ash burns. At these conditions, combustion gas temperatures are relatively low (760 to 980EC [1,400 to 1,800EF]).

In the second stage, excess air is added to the volatile gases formed in the primary chamber to complete combustion. Secondary chamber temperatures are higher than primary chamber temperatures--typically 980 to 1,095EC (1,800 to 2,000EF). Depending on the heating value and moisture content of the waste, additional heat may be needed. This can be provided by auxiliary burners located at the entrance to the secondary (upper) chamber to maintain desired temperatures.

Waste feed capacities for controlled air incinerators range from about 0.6 to 50 kg/min (75 to 6,500 lb/hr) (at an assumed fuel heating value of 19,700 kJ/kg [8,500 Btu/lb]). Waste feed and ash removal can be manual or automatic, depending on the unit size and options purchased. Throughput capacities for lower heating value wastes may be higher, since feed capacities are limited by primary



chamber heat release rates. Heat release rates for controlled air incinerators typically range from about 430,000 to 710,000 kJ/hr-m^3 (15,000 to 25,000 Btu/hr-ft^3).

Figure 2.3-1. Controlled Air Incinerator

Because of the low air addition rates in the primary chamber, and corresponding low flue gas velocities (and turbulence), the amount of solids entrained in the gases leaving the primary chamber is low. Therefore, the majority of controlled air incinerators do not have add-on gas cleaning devices.

2.3.1.2 Excess Air Incinerators -
Excess air incinerators are typically small modular units. They are also referred to as batch incinerators, multiple chamber incinerators, or "retort" incinerators. Excess air incinerators are typically a compact cube with a series of internal chambers and baffles. Although they can be operated continuously, they are usually operated in a batch mode.

Figure 2.3-2 presents a schematic for an excess air unit. Typically, waste is manually fed into the combustion chamber. The charging door is then closed, and an afterburner is ignited to bring the secondary chamber to a target temperature (typically 870 to 980°C [1600 to 1800°F]). When the target temperature is reached, the primary chamber burner ignites. The waste is dried, ignited, and combusted by heat provided by the primary chamber burner, as well as by radiant heat from the chamber walls. Moisture and volatile components in the waste are vaporized, and pass (along with combustion gases) out of the primary chamber and through a flame port which connects the primary chamber to the secondary or mixing chamber. Secondary air is added through the flame port and is mixed with the volatile components in the secondary chamber. Burners are also installed in the secondary chamber to maintain adequate temperatures for combustion of volatile gases. Gases exiting the secondary chamber are directed to the incinerator stack or to an air pollution control device. When the waste is consumed, the primary burner shuts off. Typically, the afterburner shuts off after a set time. Once the chamber cools, ash is manually removed from the primary chamber floor and a new charge of waste can be added.

Incinerators designed to burn general hospital waste operate at excess air levels of up to 300 percent. If only pathological wastes are combusted, excess air levels near 100 percent are more common. The lower excess air helps maintain higher chamber temperature when burning high- moisture waste. Waste feed capacities for excess air incinerators are usually 3.8 kg/min (500 lb/hr) or less.

2.3.1.3 Rotary Kiln Incinerators -
Rotary kiln incinerators, like the other types, are designed with a primary chamber, where waste is heated and volatilized, and a secondary chamber, where combustion of the volatile fraction is completed. The primary chamber consists of a slightly inclined, rotating kiln in which waste materials migrate from the feed end to the ash discharge end. The waste throughput rate is controlled by adjusting the rate of kiln rotation and the angle of inclination. Combustion air enters the primary chamber through a port. An auxiliary burner is generally used to start combustion and maintain desired combustion temperatures. Both the primary and secondary chambers are usually lined with acid-resistant refractory brick, as shown in the schematic drawing, Figure 2.3-3.

Volatiles and combustion gases pass from the primary chamber to the secondary chamber. The secondary chamber operates at excess air. Combustion of the volatiles is completed in the secondary chamber. Due to the turbulent motion of the waste in the primary chamber, solids burnout rates and particulate entrainment in the flue gas are higher for rotary kiln incinerators than for other incinerator designs. As a result, rotary kiln incinerators generally have add-on gas cleaning devices.

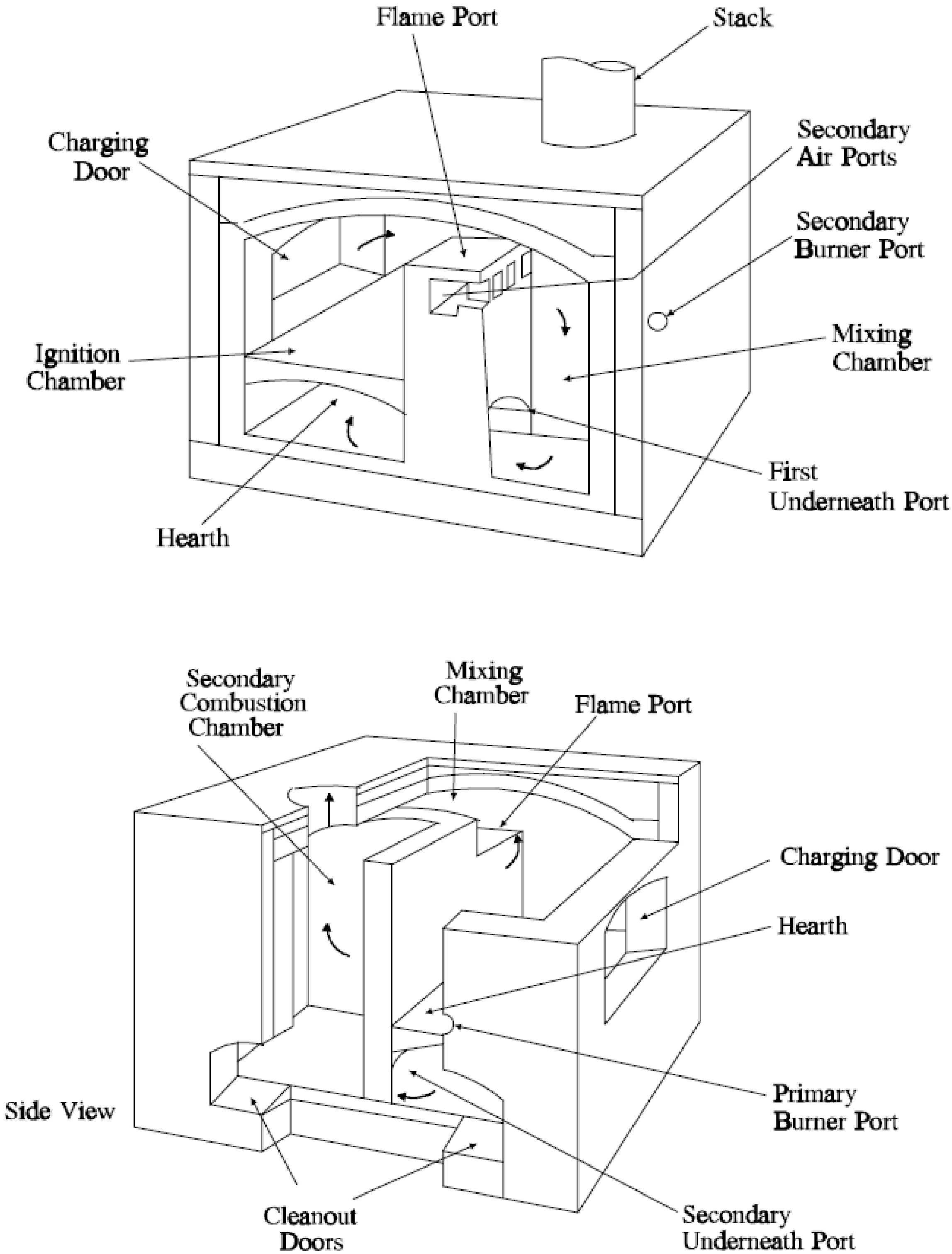


Figure 2.3-2. Excess Air Incinerator

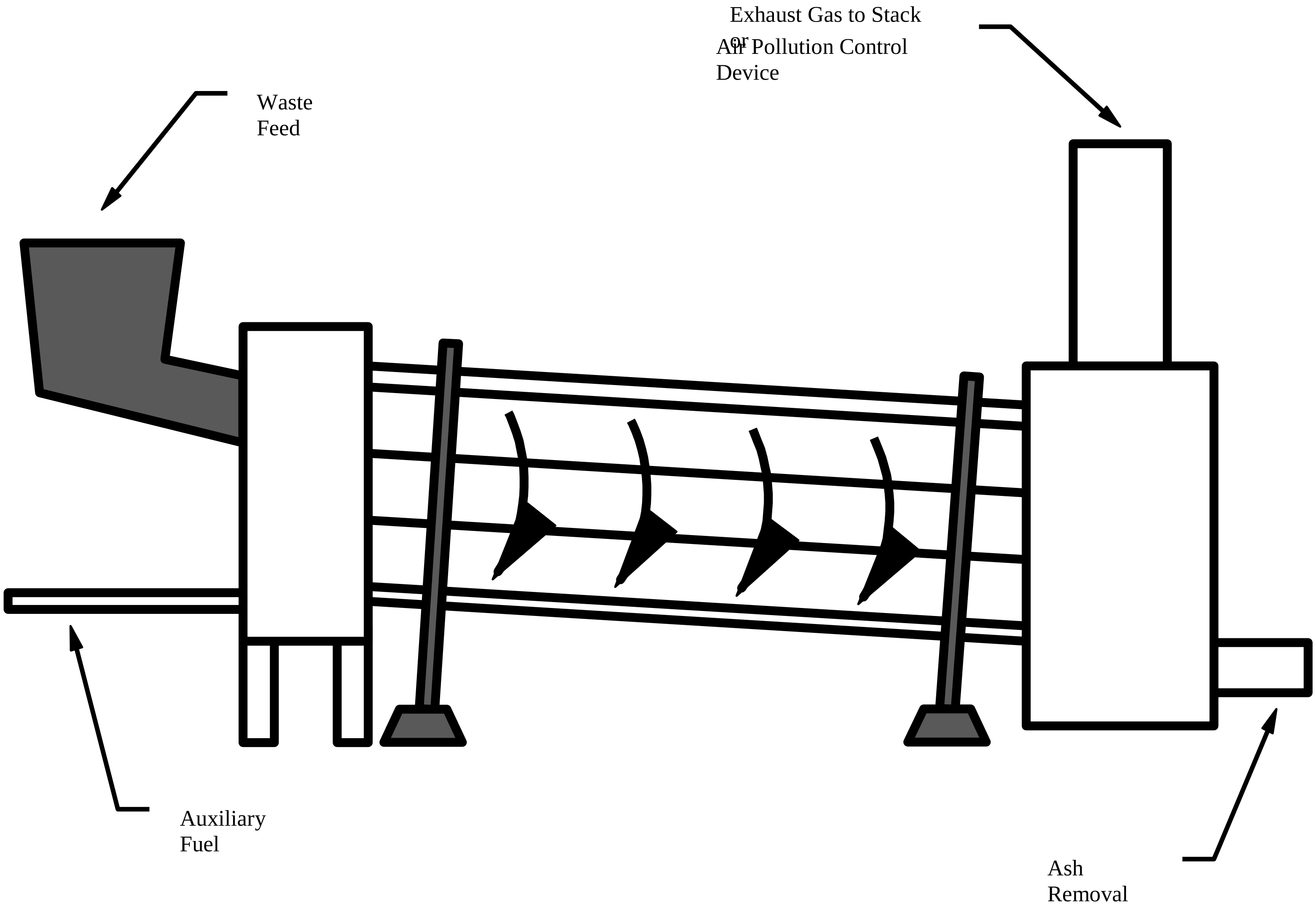


Figure 2.3-3. Rotary Kiln Incinerator

2.3.2 Emissions And Controls[2,4,7-43]

Medical waste incinerators can emit significant quantities of pollutants to the atmosphere. These pollutants include: (1) particulate matter (PM), (2) metals, (3) acid gases, (4) oxides of nitrogen (NO_x), (5) carbon monoxide (CO), (6) organics, and (7) various other materials present in medical wastes, such as pathogens, cytotoxins, and radioactive diagnostic materials.

Particulate matter is emitted as a result of incomplete combustion of organics (i. e., soot) and by the entrainment of noncombustible ash due to the turbulent movement of combustion gases. Particulate matter may exit as a solid or an aerosol, and may contain heavy metals, acids, and/or trace organics.

Uncontrolled particulate emission rates vary widely, depending on the type of incinerator, composition of the waste, and the operating practices employed. Entrainment of PM in the incinerator exhaust is primarily a function of the gas velocity within the combustion chamber containing the solid waste. Controlled air incinerators have the lowest turbulence and, consequently, the lowest PM emissions; rotary kiln incinerators have highly turbulent combustion, and thus have the highest PM emissions.

The type and amount of trace metals in the flue gas are directly related to the metals contained in the waste. Metal emissions are affected by the level of PM control and the flue gas temperature. Most metals (except mercury) exhibit fine-particle enrichment and are removed by maximizing small particle collection. Mercury, due to its high vapor pressure, does not show significant particle enrichment, and removal is not a function of small particle collection in gas streams at temperatures greater than 150EC (300EF).

Acid gas concentrations of hydrogen chloride (HCl) and sulfur dioxide (SO_2) in MWI flue gases are directly related to the chlorine and sulfur content of the waste. Most of the chlorine, which is chemically bound within the waste in the form of polyvinyl chloride (PVC) and other chlorinated compounds, will be converted to HCl. Sulfur is also chemically bound within the materials making up medical waste and is oxidized during combustion to form SO_2.

Oxides of nitrogen (NO_x) represent a mixture of mainly nitric oxide (NO) and nitrogen dioxide (NO_2). They are formed during combustion by: (1) oxidation of nitrogen chemically bound in the waste, and (2) reaction between molecular nitrogen and oxygen in the combustion air. The formation of NO_x is dependent on the quantity of fuel-bound nitrogen compounds, flame temperature, and air/fuel ratio.

Carbon monoxide is a product of incomplete combustion. Its presence can be related to insufficient oxygen, combustion (residence) time, temperature, and turbulence (fuel/air mixing) in the combustion zone.

Failure to achieve complete combustion of organic materials evolved from the waste can result in emissions of a variety of organic compounds. The products of incomplete combustion (PICs) range from low molecular weight hydrocarbon (e. g., methane or ethane) to high molecular weight compounds (e. g., polychlorinated dibenzo-p-dioxins and dibenzofurans [CDD/CDF]). In general, combustion conditions required for control of CO (i. e., adequate oxygen, temperature, residence time, and turbulence) will also minimize emissions of most organics.

Emissions of CDDs/CDFs from MWIs may occur as either a vapor or as a fine particulate. Many factors are believed to be involved in the formation of CDDs/CDFs and many theories exist concerning the formation of these compounds. In brief, the best supported theories involve four mechanisms of formation.[2] The first theory states that trace quantities of CDDs/CDFs present in the refuse feed are carried over, unburned, to the exhaust. The second theory involves formation of CDDs/CDFs from chlorinated precursors with similar structures. Conversion of precursor material to CDDs/CDFs can potentially occur either in the combustor at relatively high temperatures or at lower temperatures such as are present in wet scrubbing systems. The third theory involves synthesis of CDDs/CDFs compounds from a variety of organics and a chlorine donor. The fourth mechanism involves catalyzed reactions on fly ash particles at low temperatures.

To date, most MWIs have operated without add-on air pollution control devices (APCDs). A small percentage (approximately 2 percent) of MWIs do use APCDs. The most frequently used control devices are wet scrubbers and fabric filters (FFs). Fabric filters provide mainly PM control. Other PM control technologies include venturi scrubbers and electrostatic precipitators (ESPs). In addition to wet scrubbing, dry sorbent injection (DSI) and spray dryer (SD) absorbers have also been used for acid gas control.

Wet scrubbers use gas-liquid absorption to transfer pollutants from a gas to a liquid stream. Scrubber design and the type of liquid solution used largely determine contaminant removal efficiencies. With plain water, removal efficiencies for acid gases could be as high as 70 percent for HCl and 30 percent for SO_2. Addition of an alkaline reagent to the scrubber liquor for acid neutralization has been shown to result in removal efficiencies of 93 to 96 percent.

Wet scrubbers are generally classified according to the energy required to overcome the pressure drop through the system. Low-energy scrubbers (spray towers) are primarily used for acid gas control only, and are usually circular in cross section. The liquid is sprayed down the tower through the rising gas. Acid gases are absorbed/neutralized by the scrubbing liquid. Low-energy scrubbers mainly remove particles larger than 5-10 micrometers (Φm) in diameter.

Medium-energy scrubbers can be used for particulate matter and/or acid gas control. Medium energy devices rely mostly on impingement to facilitate removal of PM. This can be accomplished through a variety of configurations, such as packed columns, baffle plates, and liquid impingement scrubbers.

Venturi scrubbers are high-energy systems that are used primarily for PM control. A typical venturi scrubber consists of a converging and a diverging section connected by a throat section. A liquid (usually water) is introduced into the gas stream upstream of the throat. The flue gas impinges on the liquid stream in the converging section. As the gas passes through the throat, the shearing action atomizes the liquid into fine droplets. The gas then decelerates through the diverging section, resulting in further contact between particles and liquid droplets. The droplets are then removed from the gas stream by a cyclone, demister, or swirl vanes.

A fabric filtration system (baghouse) consists of a number of filtering elements (bags) along with a bag cleaning system contained in a main shell structure with dust hoppers. Particulate-laden gas passes through the bags so that the particles are retained on the upstream side of the fabric, thus cleaning the gas. A FF is typically divided into several compartments or sections. In a FF, both the collection efficiency and the pressure drop across the bag surface increase as the dust layer on the bag builds up. Since the system cannot continue to operate with an increasing pressure drop, the bags are cleaned periodically. The cleaning processes include reverse flow with bag collapse, pulse jet cleaning, and mechanical shaking. When reverse flow and mechanical shaking are used, the particulate matter is collected on the inside of the bag; particulate matter is collected on the outside of the bag in pulse jet systems. Generally, reverse flow FFs operate with lower gas flow per unit area of bag surface (air-to-cloth ratio) than pulse jet systems and, thus, are larger and more costly for a given gas flow-rate or application. Fabric filters can achieve very high (>99.9 percent) PM removal efficiencies. These systems are also very effective in controlling fine particulate matter, which results in good control of metals and organics entrained on fine particulate.

Particulate collection in an ESP occurs in 3 steps: (1) suspended particles are given an electrical charge; (2) the charged particles migrate to a collecting electrode of opposite polarity; and (3) the collected PM is dislodged from the collecting electrodes and collected in hoppers for disposal.

Charging of the particles is usually caused by ions produced in a high voltage corona. The electric fields and the corona necessary for particle charging are provided by converting alternating current to direct current using high voltage transformers and rectifiers. Removal of the collected particulate matter is accomplished mechanically by rapping or vibrating the collecting electrode plates. ESPs have been used in many applications due to their high reliability and efficiency in controlling total PM emissions. Except for very large and carefully designed ESPs, however, they are less efficient than FFs at control of fine particulates and metals.

Dry sorbent injection (DSI) is another method for controlling acid gases. In the DSI process, a dry alkaline material is injected into the flue gas into a dry venturi within the ducting or into the duct ahead of a particulate control device. The alkaline material reacts with and neutralizes acids in the flue gas. Fabric filters are employed downstream of DSI to: (1) control the PM generated by the incinerator, (2) capture the DSI reaction products and unreacted sorbent, and (3) increase sorbent/acid gas contact time, thus enhancing acid gas removal efficiency and sorbent utilization. Fabric filters are commonly used with DSI because they provide high sorbent/acid gas contact. Fabric filters are less sensitive to PM loading changes or combustion upsets than other PM control devices since they operate with nearly constant efficiency. A potential disadvantage of ESPs used in conjunction with DSI is that the sorbent increases the electrical resistivity of the PM being collected. This phenomenon makes the PM more difficult to charge and, therefore, to collect. High resistivity can be compensated for by flue gas conditioning or by increasing the plate area and size of the ESP.

The major factors affecting DSI performance are flue gas temperature, acid gas dew point (temperature at which the acid gases condense), and sorbent-to-acid gas ratio. DSI performance improves as the difference between flue gas and acid dew point temperatures decreases and the sorbent-to-acid gas ratio increases. Acid gas removal efficiency with DSI also depends on sorbent type and the extent of sorbent mixing with the flue gas. Sorbents that have been successfully applied include hydrated lime ($Ca[OH]_2$), sodium hydroxide (NaOH), and sodium bicarbonate ($NaHCO_3$). For hydrated lime, DSI can achieve 80 to 95 percent of HCl removal and 40 to 70 percent removal of SO_2 under proper operating conditions.

The primary advantage of DSI compared to wet scrubbers is the relative simplicity of the sorbent preparation, handling, and injection systems as well as the easier handling and disposal of dry solid process wastes. The primary disadvantages are its lower sorbent utilization rate and correspondingly higher sorbent and waste disposal rates.

In the spray drying process, lime slurry is injected into the SD through either a rotary atomizer or dual-fluid nozzles. The water in the slurry evaporates to cool the flue gas, and the lime reacts with acid gases to form calcium salts that can be removed by a PM control device. The SD is designed to provide sufficient contact and residence time to produce a dry product before leaving the SD adsorber vessel. The residence time in the adsorber vessel is typically 10 to 15 seconds. The particulates leaving the SD (fly ash, calcium salts, and unreacted hydrated lime) are collected by an FF or ESP.

Emission factors and emission factor ratings for controlled air incinerators are presented in Tables 2.3-1, 2.3-2, 2.3-3, 2.3-4, 2.3-5, 2.3-6, 2.3-7, 2.3-8, 2.3-9, 2.3-10, 2.3-11, 2.3-12, 2.3-13, 2.13-14, and 2.3-15. For emissions controlled with wet scrubbers, emission factors are presented separately for low-, medium-, and high-energy wet scrubbers. Particle size distribution data for controlled air incinerators are presented in Table 2.3-15 for uncontrolled emissions and controlled emissions following a medium-energy wet scrubber/FF and a low-energy wet scrubber. Emission factors and emission factor ratings for rotary kiln incinerators are presented in Tables 2.3-16, 2.3-17, and 2.3-18. Emissions data are not available for pathogens because there is not an accepted methodology for measurement of these emissions. Refer to References 8, 9, 11, 12, and 19 for more information.

Table 2.3-1 (English And Metric Units). EMISSION FACTORS FOR NITROGEN OXIDES (NO_x), CARBON MONOXIDE (CO), AND SULFUR DIOXIDE (SO_2) FOR CONTROLLED AIR MEDICAL WASTE INCINERATORS[a]

Rating (A-E) Follows Each Factor

Control Level[b]	NO_x[c]			CO[c]			SO_2[c]		
	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING
Uncontrolled	3.56 E+00	1.78 E+00	A	2.95 E+00	1.48 E+00	A	2.17 E+00	1.09 E+00	B
Low Energy Scrubber/FF									
Medium Energy Scrubber/FF							3.75 E-01	1.88 E-01	E
FF							8.45 E-01	4.22 E-01	E
Low Energy Scrubber							2.09 E+00	1.04 E+00	E
High Energy Scrubber							2.57 E-02	1.29 E-02	E
DSI/FF							3.83 E-01	1.92 E-01	E
DSI/Carbon Injection/FF							7.14 E-01	3.57 E-01	E
DSI/FF/Scrubber							1.51 E-02	7.57 E-03	E
DSI/ESP									

[a] References 7-43. Source Classification Codes 5-01-005-05, 5-02-005-05. Blanks indicate no data.
[b] FF = Fabric Filter
DSI = Dry Sorbent Injection
ESP = Electrostatic Precipitator
[c] NO_x and CO emission factors for uncontrolled facilities are applicable for all add-on control devices shown.

Table 2.3-2 (English And Metric Units). EMISSION FACTORS FOR TOTAL PARTICULATE MATTER, LEAD, AND TOTAL ORGANIC COMPOUNDS (TOC) FOR CONTROLLED AIR MEDICAL WASTE INCINERATORS[a]

Rating (A-E) Follows Each Factor

Control Level[b]	Total Particulate Matter			Lead[c]			TOC		
	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING
Uncontrolled	4.67 E+00	2.33 E+00	B	7.28 E-02	3.64 E-02	B	2.99 E-01	1.50 E-01	B
Low Energy Scrubber/FF	9.09 E-01	4.55 E-01	E						
Medium Energy Scrubber/FF	1.61 E-01	8.03 E-02	E	1.60 E-03	7.99 E-04	E			
FF	1.75 E-01	8.76 E-02	E	9.92 E-05	4.96 E-05	E	6.86 E-02	3.43 E-01	E
Low Energy Scrubber	2.90 E+00	1.45 E+00	E	7.94 E-02	3.97 E-02	E	1.40 E-01	7.01 E-02	E
High Energy Scrubber	1.48 E+00	7.41 E-01	E	6.98 E-02	3.49 E-02	E	1.40 E-01	7.01 E-02	E
DSI/FF	3.37 E-01	1.69 E-01	E	6.25 E-05	3.12 E-05*	E	4.71 E-02	2.35 E-02	E
DSI/Carbon Injection/FF	7.23 E-02	3.61 E-02	E	9.27 E-05	4.64 E-05	E			
DSI/FF/Scrubber	2.68 E+00	1.34 E+00	E	5.17 E-05	2.58 E-05	E			
DSI/ESP	7.34 E-01	3.67 E-01	E	4.70 E-03	2.35 E-03	E			

[a] References 7-43. Source Classification Codes 5-01-005-05, 5-02-005-05. Blanks indicate no data.
[b] FF = Fabric Filter
DSI = Dry Sorbent Injection
ESP = Electrostatic Precipitator
[c] Hazardous air pollutants listed in the *Clean Air Act.*
*Conversion corrected 10/30/17

Table 2.3-3 (English And Metric Units). EMISSION FACTORS FOR HYDROGEN CHLORIDE (HCl) AND POLYCHLORINATED BIPHENYLS (PCBs) FOR CONTROLLED AIR MEDICAL WASTE INCINERATORS[a]

Rating (A-E) Follows Each Factor

Control Level[b]	HCl[c]			Total PCBs[c]		
	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING
Uncontrolled	3.35 E+01	1.68 E+01	C	4.65 E-05	2.33 E-05	E
Low Energy Scrubber/FF	1.90 E+00	9.48 E-01	E			
Medium Energy Scrubber/FF	2.82 E+00	1.41 E+00	E			
FF	5.65 E+00	2.82 E+00	E			
Low Energy Scrubber	1.00 E+00	5.01 E-01	E			
High Energy Scrubber	1.39 E-01	6.97 E-02	E			
DSI/FF	1.27 E+01	6.37 E+00	D			
DSI/Carbon Injection/FF	9.01 E-01	4.50 E-01	E			
DSI/FF/Scrubber	9.43 E-02	4.71 E-02	E			
DSI/ESP	4.98 E-01	2.49 E-01	E			

[a] References 7-43. Source Classification Codes 5-01-005-05, 5-02-005-05. Blanks indicate no data.
[b] FF = Fabric Filter
DSI = Dry Sorbent Injection
ESP = Electrostatic Precipitator
[c] Hazardous air pollutants listed in the *Clean Air Act*.

Table 2.3-4 (English And Metric Units). EMISSION FACTORS FOR ALUMINUM, ANTIMONY, AND ARSENIC CONTROLLED AIR MEDICAL WASTE INCINERATORS[a]

Rating (A-E) Follows Each Factor

Control Level[b]	Aluminum			Antimony[c]			Arsenic[c]		
	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING
Uncontrolled	1.05 E-02	5.24 E-03	E	1.28 E-02	6.39 E-03	D	2.42 E-04	1.21 E-04	B
Low Energy Scrubber/FF									
Medium Energy Scrubber/FF				3.09 E-04	1.55 E-04	E	3.27 E-05	1.53 E-02	E
FF							3.95 E-08	1.97 E-08	E
Low Energy Scrubber							1.42 E-04	7.12 E-05	E
High Energy Scrubber				4.08 E-04	2.04 E-04	E	3.27 E-05	1.64 E-05	E
DSI/FF	3.03 E-03	1.51 E-03	E	2.10 E-04	1.05 E-04	E	1.19 E-05	5.93 E-06	E
DSI/Carbon Injection/FF	2.99 E-03	1.50 E-03	E	1.51 E-04	7.53 E-05	E	1.46 E-05	7.32 E-06	E
DSI/FF/Scrubber									
DSI/ESP							5.01 E-05	2.51 E-05	E

[a] References 7-43. Source Classification Codes 5-01-005-05, 5-02-005-05. Blanks indicate no data.
[b] FF = Fabric Filter
DSI = Dry Sorbent Injection
ESP = Electrostatic Precipitator
[c] Hazardous air pollutants listed in the *Clean Air Act*.

Table 2.3-5 (English And Metric Units). EMISSION FACTORS FOR BARIUM, BERYLLIUM, AND CADMIUM FOR CONTROLLED AIR MEDICAL WASTE INCINERATORS[a]

Rating (A-E) Follows Each Factor

Control Level[b]	Barium			Beryllium[c]			Cadmium[c]		
	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING
Uncontrolled	3.24 E-03	1.62 E-03	D	6.25 E-06	3.12 E-06	D	5.48 E-03	2.74 E-03	B
Low Energy Scrubber/FF									
Medium Energy Scrubber/FF	2.07 E-04	1.03 E-04	E				1.78 E-04	8.89 E-05	E
FF									
Low Energy Scrubber							6.97 E-03	3.49 E-03	E
High Energy Scrubber							7.43 E-02	3.72 E-02	E
DSI/FF	7.39 E-05	3.70 E-05	E				2.46 E-05	1.23 E-05	E
DSI/Carbon Injection/FF	7.39 E-05	3.69 E-05	E	3.84 E-06	1.92 E-06	E	9.99 E-05	4.99 E-05	E
DSI/FF/Scrubber							1.30 E-05	6.48 E-06	E
DSI/ESP							5.93 E-04	2.97 E-04	E

[a] References 7-43. Source Classification Codes 5-01-005-05, 5-02-005-05. Blanks indicate no data.
[b] FF = Fabric Filter
DSI = Dry Sorbent Injection
ESP = Electrostatic Precipitator
[c] Hazardous air pollutants listed in the *Clean Air Act*.

Table 2.3-6 (English And English Units). EMISSION FACTORS FOR CHROMIUM, COPPER, AND IRON FOR CONTROLLED AIR MEDICAL WASTE INCINERATORS[a]

Rating (A-E) Follows Each Factor

Control Level[b]	Chromium[c]			Copper			Iron		
	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING
Uncontrolled	7.75 E-04	3.88 E-04	B	1.25 E-02	6.24 E-03	E	1.44 E-02	7.22 E-03	C
Low Energy Scrubber/FF									
Medium Energy Scrubber/FF	2.58 E-04	1.29 E-04	E						
FF	2.15 E-06	1.07 E-06	E						
Low Energy Scrubber	4.13 E-04	2.07 E-04	E				9.47 E-03	4.73E -03	E
High Energy Scrubber	1.03 E-03	5.15 E-04	E						
DSI/FF	3.06 E-04	1.53 E-04	E	1.25 E-03	6.25 E-04	E			
DSI/Carbon Injection/FF	1.92 E-04	9.58 E-05	E	2.75 E-04	1.37 E-04	E			
DSI/FF/Scrubber	3.96 E-05	1.98 E-05	E						
DSI/ESP	6.58 E-04	3.29 E-04	E						

[a] References 7-43. Source Classification Codes 5-01-005-05, 5-02-005-05. Blanks indicate no data.
[b] FF = Fabric Filter
DSI = Dry Sorbent Injection
ESP = Electrostatic Precipitator
[c] Hazardous air pollutants listed in the *Clean Air Act*.

Table 2.3-7 (English and Metric Units). EMISSION FACTORS FOR MANGANESE, MERCURY, AND NICKEL FOR CONTROLLED AIR MEDICAL WASTE INCINERATORS[a]

Rating (A-E) Follows Each Factor

Control Level[b]	Manganese[c]			Mercury[c]			Nickel[c]		
	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING
Uncontrolled	5.67 E-04	2.84 E-04	C	1.07 E-01	5.37 E-02	C	5.90 E-04	2.95 E-04	B
Low Energy Scrubber/FF									
Medium Energy Scrubber/FF				3.07 E-02	1.53 E-02	E	5.30 E-04	2.65 E-04	E
FF									
Low Energy Scrubber	4.66 E-04	2.33 E-04	E	1.55 E-02	7.75 E-03	E	3.28 E-04	1.64 E-02	E
High Energy Scrubber	6.12 E-04	3.06 E-04	E	1.73 E-02	8.65 E-03	E	2.54 E-03	1.27 E-03	E
DSI/FF				1.11 E-01	5.55 E-02	E	4.54 E-04	2.27 E-04	E
DSI/Carbon Injection/FF				9.74 E-03	4.87 E-03	E	2.84 E-04	1.42 E-04	E
DSI/FF/Scrubber				3.56 E-04	1.78 E-04	E			
DSI/ESP				1.81 E-02	9.05 E-03	E	4.84 E-04	2.42 E-04	E

[a] References 7-43. Source Classification Codes 5-01-005-05, 5-02-005-05. Blanks indicate no data.
[b] FF = Fabric Filter
DSI = Dry Sorbent Injection
ESP = Electrostatic Precipitator
[c] Hazardous air pollutants listed in the *Clean Air Act*.

Table 2.3-8 (English And Metric Units). EMISSION FACTORS FOR SILVER AND THALLIUM FOR CONTROLLED AIR MEDICAL WASTE INCINERATORS[a]
Rating (A-E) Follows Each Factor

Control Level[b]	Silver			Thallium		
	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING
Uncontrolled	2.26 E-04	1.13 E-04	D	1.10 E-03	5.51 E-04	D
Low Energy Scrubber/FF						
Medium Energy Scrubber/FF	1.71 E-04	8.57 E-05	E			
FF						
Low Energy Scrubber						
High Energy Scrubber	4.33 E-04	2.17 E-04	E			
DSI/FF	6.65 E-05	3.32 E-05	E			
DSI/Carbon Injection/FF	7.19 E-05	3.59 E-05	E			
DSI/FF/Scrubber						
DSI/ESP						

[a] References 7-43. Source Classification Codes 5-01-005-05, 5-02-005-05. Blanks indicate no data.
[b] FF = Fabric Filter
DSI = Dry Sorbent Injection
ESP = Electrostatic Precipitator

Table 2.3-9 (English And Metric Units). EMISSION FACTORS FOR SULFUR TRIOXIDE (SO_3) AND HYDROGEN BROMIDE (HBr) FOR CONTROLLED AIR MEDICAL WASTE INCINERATORS[a]

Rating (A-E) Follows Each Factor

Control Level[b]	SO_3			HBr		
	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING
Uncontrolled				4.33 E-02	2.16 E-02	D
Low Energy Scrubber/FF						
Medium Energy Scrubber/FF				5.24 E-02	2.62 E-02	E
FF						
Low Energy Scrubber						
High Energy Scrubber						
DSI/FF						
DSI/Carbon Injection/FF				4.42 E-03	2.21 E-03	E
DSI/FF/Scrubber	9.07 E-03	4.53 E-03	E			
DSI/ESP						

[a] References 7-43. Source Classification Codes 5-01-005-05, 5-02-005-05. Blanks indicate no data.
[b] FF = Fabric Filter
DSI = Dry Sorbent Injection
ESP = Electrostatic Precipitator

Table 2.3-10 (English And Metric Units). EMISSION FACTORS FOR HYDROGEN FLUORIDE AND CHLORINE FOR CONTROLLED AIR MEDICAL WASTE INCINERATORS[a]

Rating (A-E) Follows Each Factor

Control Level[b]	Hydrogen Fluoride[c]			Chlorine[c]		
	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING
Uncontrolled	1.49 E-01	7.43 E-02	D	1.05 E-01	5.23 E-02	E
Low Energy Scrubber/FF						
Medium Energy Scrubber/FF						
FF						
Low Energy Scrubber						
High Energy Scrubber						
DSI/FF						
DSI/Carbon Injection/FF	1.33 E-02	6.66 E-03	E			
DSI/FF/Scrubber						
DSI/ESP						

[a] References 7-43. Source Classification Codes 5-01-005-05, 5-02-005-05. Blanks indicate no data.
[b] FF = Fabric Filter
DSI = Dry Sorbent Injection
ESP = Electrostatic Precipitator
[c] Hazardous air pollutants listed in the *Clean Air Act*.

Table 2.3-11 (English And Metric Units). CHLORINATED DIBENZO-P-DIOXIN EMISSION FACTORS FOR CONTROLLED AIR MEDICAL WASTE INCINERATORS[a]

Rating (A-E) Follows Each Factor

Congener[b]	Uncontrolled			Fabric Filter			Wet Scrubber			DSI/FF[c]		
	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING
TCDD												
2,3,7,8-	5.47 E-08	2.73 E-08	E	6.72 E-09	3.36 E-09	E	1.29 E-10	6.45 E-11	E	5.61 E-10	2.81 E-10	E
Total	1.00 E-06	5.01 E-07	B	1.23 E-07	6.17 E-08	E	2.67 E-08	1.34 E-08	E	6.50 E-09	3.25 E-09	E
PeCDD												
1,2,3,7,8-							6.08 E-10	3.04 E-10	E			
Total							5.53 E-10	2.77 E-10	E			
HxCDD												
1,2,3,6,7,8-	3.78 E-10	1.89 E-10	E				1.84 E-09	9.05 E-10	E			
1,2,3,7,8,9-	1.21 E-09	6.07 E-10	E				2.28 E-09	1.14 E-09	E			
1,2,3,4,7,8-							9.22 E-10	4.61 E-10	E			
Total							5.77 E-10	2.89 E-10	E			
HpCDD												
1,2,3,4,6,7,8-	5.23 E-09	2.62 E-09	E				6.94 E-09	3.47 E-09	E			
Total							1.98 E-09	9.91 E-10	E			
OCDD - total	2.21 E-08	1.11 E-08	E									
Total CDD	2.13 E-05	1.07 E-05	B	2.68 E-06	1.34 E-06	E	1.84 E-06	9.18 E-07	E	3.44 E-07	1.72 E-07	E

[a] References 7-43. Source Classification Codes 5-01-005-05, 5-02-005-05. Blanks indicate no data.

[b] Hazardous air pollutants listed in *Clean Air Act*.

[c] FF = Fabric Filter
DSI = Dry Sorbent Injection

Table 2.3-12 (English And Metric Units). CHLORINATED DIBENZO-P-DIOXIN EMISSION FACTORS FOR CONTROLLED AIR MEDICAL WASTE INCINERATORS[a]

Rating (A-E) Follows Each Factor

Congener[b]	DSI/Carbon Injection/FF[c]			DSI/ESP[d]		
	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING
TCDD						
2,3,7,8-	8.23 E-10	4.11 E-10	E	1.73 E-10	8.65 E-11	E
Total						
PeCDD						
1,2,3,7,8-						
Total						
HxCDD						
1,2,3,6,7,8-						
1,2,3,7,8,9-						
1,2,3,4,7,8-						
Total						
HpCDD						
2,3,4,6,7,8-						
1,2,3,4,6,7,8-						
Total						
OCDD - Total						
Total CDD	5.38 E-08	2.69 E-08	E			

[a] References 7-43. Source Classification Codes 5-01-005-05, 5-02-005-05. Blanks indicate no data.
[b] Hazardous air pollutants listed in the *Clean Air Act*.
[c] FF = Fabric Filter
DSI = Dry Sorbent Injection
[d] ESP = Electrostatic Precipitator

Table 2.3-13 (English And Metric Units). CHLORINATED DIBENZOFURAN EMISSION FACTORS FOR CONTROLLED AIR MEDICAL WASTE INCINERATORS[a]

Rating (A-E) Follows Each Factor

Congener[b]	Uncontrolled			Fabric Filter			Wet Scrubber			DSI/FF[c]		
	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING
TCDF												
2,3,7,8-	2.40 E-07	1.20 E-07	E	3.85 E-08	1.97 E-08	E	1.26 E-08	6.30 E-09	E	4.93 E-09	2.47 E-09	E
Total	7.21 E-06	3.61 E-06	B	1.28 E-06	6.39 E-07	E	4.45 E-07	2.22 E-07	E	1.39 E-07	6.96 E-08	E
PeCDF												
1,2,3,7,8-	7.56 E-10	3.78 E-10	E				1.04 E-09	5.22 E-10	E			
2,3,4,7,8-	2.07 E-09	1.04 E-09	E				3.07 E-09	1.53 E-09	E			
Total							6.18 E-09	3.09 E-09	E			
HxCDF												
1,2,3,4,7,8-	7.55 E-09	3.77 E-09	E				8.96 E-09	4.48 E-09	E			
1,2,3,6,7,8-	2.53 E-09	1.26 E-09	E				3.53 E-09	1.76 E-09	E			
2,3,4,6,7,8-	7.18 E-09	3.59 E-09	E				9.59 E-09	4.80 E-09	E			
1,2,3,7,8,9-							3.51 E-10	1.76 E-10	E			
Total							5.10 E-09	2.55 E-09	E			
HpCDF												
1,2,3,4,6,7,8-	1.76 E-08	8.78 E-09	E				1.79 E-08	8.97 E-09	E			
1,2,3,4,7,8,9-	2.72 E-09	1.36 E-09	E				3.50 E-09	1.75 E-09	E			
Total							1.91 E-09	9.56 E-10	E			
OCDF - Total	7.42 E-08	3.71 E-08	E				4.91 E-10	2.45 E-10	E			
Total CDF	7.15 E-05	3.58 E-05	B	8.50 E-06	4.25 E-06	E	4.92 E-06	2.46 E-06	E	1.47 E-06	7.37 E-07	E

[a] References 7-43. Source Classification Codes 5-01-005-05, 5-02-005-05. Blanks indicate no data.

[b] Hazardous air pollutants listed in the *Clean Air Act*.

[c] FF = Fabric Filter
DSI = Dry Sorbent Injection

[d] ESP = Electrostatic Precipitator

Table 2.3-14 (English And Metric Units). CHLORINATED DIBENZOFURANS EMISSION FACTORS FOR CONTROLLED AIR MEDICAL WASTE INCINERATORS[a]

Rating (A-E) Follows Each Factor

Congener[b]	DSI/Carbon Injection/FF[c]			DSI/ESP[d]		
	lb/ton	kg/Mg	EMISSION FACTOR RATING	lb/ton	kg/Mg	EMISSION FACTOR RATING
TCDF						
2,3,7,8-	7.31 E-10	3.65 E-10	E	1.73 E-09	8.66 E-10	E
Total	1.01 E-08	5.07 E-09	E			
PeCDF						
1,2,3,7,8-						
2,3,4,7,8-						
Total						
HxCDF						
1,2,3,4,7,8-						
1,2,3,6,7,8-						
2,3,4,6,7,8-						
1,2,3,7,8,9-						
Total						
HpCDF						
1,2,3,4,6,7,8-						
1,2,3,4,7,8,9-						
Total						
OCDF - Total						
Total CDF	9.47 E-08	4.74 E-08	E			

[a] References 7-43. Source Classification Codes 5-01-005-05, 5-02-005-05. Blanks indicate no data.
[b] Hazardous air pollutants listed in the *Clean Air Act*.
[c] FF = Fabric Filter
DSI = Dry Sorbent Injection
[d] ESP = Electrostatic Precipitator

Table 2.3-15. PARTICLE SIZE DISTRIBUTION FOR CONTROLLED AIR MEDICAL WASTE INCINERATOR PARTICULATE MATTER EMISSIONS[a]

EMISSION FACTOR RATING: E

Cut Diameter (µm)	Uncontrolled Cumulative Mass % Less Than Stated Size	Scrubber Cumulative Mass % Less Than Stated Size
0.625	31.1	0.1
1.0	35.4	0.2
2.5	43.3	2.7
5.0	52.0	28.1
10.0	65.0	71.9

[a] References 7-43. Source Classification Codes 5-01-005-05, 5-02-005-05

Table 2.3-16 (English And Metric Units). ROTARY KILN MEDICAL WASTE INCINERATOR EMISSION FACTORS FOR CRITERIA POLLUTANTS AND ACID GASES[a]

EMISSION FACTOR RATING: E

Pollutant	Uncontrolled		SD/Fabric Filter[b]		SD/Carbon Injection/FF[c]		High Energy Scrubber	
	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg
Carbon monoxide	3.82 E-01	1.91 E-01	3.89 E-02	1.94 E-02	4.99 E-02	2.50 E-02	5.99 E-02	3.00 E-02
Nitrogen oxides	4.63 E+00	2.31 E+00	5.25 E+00	2.63 E+00	4.91 E+00	2.45 E+00	4.08 E+00	2.04 E+00
Sulfur dioxide	1.09 E+00	5.43 E-01	6.47 E-01	3.24 E-01	3.00 E-01	1.50 E-01		
PM	3.45 E+01	1.73 E+01	3.09 E-01	1.54 E-01	7.56 E-02	3.78 E-02	8.53 E-01	4.27 E-01
TOC	6.66 E-02	3.33 E-02	4.11 E-02	2.05 E-02	5.05 E-02	2.53 E-02	2.17 E-02	1.08 E-02
HCl[d]	4.42 E+01	2.21 E+01	2.68 E-01	1.34 E-01	3.57 E-01	1.79 E-01	2.94 E+01	1.47 E+01
HF[d]	9.31 E-02	4.65 E-02	2.99 E-02	1.50 E-02				
HBr	1.05 E+00	5.25 E-01	6.01 E-02	3.00 E-02	1.90 E-02	9.48 E-03		
H_2SO_4							2.98 E+00	1.49 E+00

[a] References 7-43. Source Classification Codes 5-01-005-05, 5-02-005-05. Blanks indicate no data.
[b] SD = Spray Dryer
[c] FF = Fabric Filter
[d] Hazardous air pollutant listed in the *Clean Air Act.*

Table 2.3-17 (English And Metric Units). ROTARY KILN MEDICAL WASTE INCINERATOR EMISSION FACTORS FOR METALS[a]

EMISSION FACTOR RATING: E

Pollutant	Uncontrolled		SD/Fabric Filter[b]		SD/Carbon Injection/FF[c]	
	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg
Aluminum	6.13 E-01	3.06 E-01	4.18 E-03	2.09 E-03	2.62 E-03	1.31 E-03
Antimony[d]	1.99 E-02	9.96 E-03	2.13 E-04	1.15 E-04	1.41 E-04	7.04 E-05
Arsenic[d]	3.32 E-04	1.66 E-04				
Barium	8.93 E-02	4.46 E-02	2.71 E-04	1.35 E-04	1.25 E-04	6.25 E-05
Beryllium[d]	4.81 E-05	2.41 E-05	5.81 E-06	2.91 E-06		
Cadmium[d]	1.51 E-02	7.53 E-03	5.36 E-05	2.68 E-05	2.42 E-05	1.21 E-05
Chromium[d]	4.43 E-03	2.21 E-03	9.85 E-05	4.92 E-05	7.73 E-05	3.86 E-05
Copper	1.95 E-01	9.77 E-02	6.23 E-04	3.12 E-04	4.11 E-04	2.06 E-04
Lead[d]	1.24 E-01	6.19 E-02	1.89 E-04	9.47 E-05	7.38 E-05	3.69 E-05
Mercury[d]	8.68 E-02	4.34 E-02	6.65 E-02	3.33 E-02	7.86 E-03	3.93 E-03
Nickel[d]	3.53 E-03	1.77 E-03	8.69 E-05	4.34 E-05	3.58 E-05	1.79 E-05
Silver	1.30 E-04	6.51 E-05	9.23 E-05	4.61 E-05	8.05 E-05	4.03 E-05
Thallium	7.58 E-04	3.79 E-04				

[a] References 7-43. Source Classification Codes 5-01-005-05, 5-02-005-05. ND = no data. Blanks indicate no data.
[b] SD = Spray Dryer.
[c] FF = Fabric Filter.
[d] Hazardous air pollutant listed in the *Clean Air Act*.

Table 2.3-18 (English And Metric Units). ROTARY KILN MEDICAL WASTE INCINERATOR EMISSION FACTORS FOR DIOXINS AND FURANS[a]

EMISSION FACTOR RATING: E

Congener[d]	Uncontrolled		SD/Fabric Filter[b]		SD/Carbon Injection/FF[c]	
	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg
2,3,7,8-TCDD	6.61 E-10	3.30 E-10	4.52 E-10	2.26 E-10	6.42 E-11	3.21 E-11
Total TCDD	7.23 E-09	3.61 E-09	4.16 E-09	2.08 E-09	1.55 E-10	7.77 E-11
Total CDD	7.49 E-07	3.75 E-07	5.79 E-08	2.90 E-08	2.01 E-08	1.01 E-08
2,3,7,8-TCDF	1.67 E-08	8.37 E-09	1.68 E-08	8.42 E-09	4.96 E-10	2.48 E-10
Total TCDF	2.55 E-07	1.27 E-07	1.92 E-07	9.58 E-08	1.15 E-08	5.74 E-09
Total CDF	5.20 E-06	2.60 E-06	7.91 E-07	3.96 E-07	7.57 E-08	3.78 E-08

[a] References 7-43. Source Classification Codes 5-01-005-05, 5-02-005-05.
[b] SD = Spray Dryer.
[c] FF = Fabric Filter.
[d] Hazardous air pollutants listed in the *Clean Air Act*.

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