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Review

Medical waste management/incineration

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Abstract

Major changes in medical waste disposal practices are expected to occur in the future because of regulatory requirements from both the Federal and State level; namely:

- At the Federal level, under the Clean Air Act of 1970 and its recently enacted Amendments of 1990, EPA proposed air emission standards to regulate medical waste incineration in February 1995.
- At the State level, many States are developing new standards to control medical waste disposal.

Because of the information need to support the implementation of the regulations, both the Federal Government and the States have conducted various studies. This paper represents a discussion of what has been learned as a result of these studies. Major activities have included:

- EPA's/Risk Reduction Engineering Laboratory's (RREL's) State-of-the-Art Assessment of Medical Waste Thermal Treatment;
- Four medical waste management workshops co-sponsored by EPA's RREL, EPA's Office of Solid Waste (OSW), and the California Air Resources Board;
- Field tests of medical waste incinerator performance conducted by EPA and the States;
- Evaluation of medical waste treatment technologies conducted by private industries;
- The promulgation of medical waste incineration standards by several States and the active development of Federal standards by EPA's Office of Air Quality Planning and Standards (OAQPS); and
- EPA's/OSW's submittal of their first Interim Report to Congress.

Keywords: Medical waste; Incineration; Treatment technologies; Health issues

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1. Introduction

Medical waste refers to any waste generated from the health care industry such as hospitals and medical laboratories. It includes anatomical waste, pathological waste, infectious waste, hazardous waste, and other waste. Because of the recent AIDS (acquired immune deficiency syndrome) dilemma and that posed by other communicable diseases such as hepatitis B, the public is increasingly concerned over the handling of medical waste.

Prior to 1988, disposal of medical waste had been regulated entirely by State regulations. However, because of the medical waste wash-up onto beaches during the summers of 1987 and 1988, the public responded with a very strong concern over the adequacy of medical waste disposal regulations. As a result, Congress enacted the Medical Waste Tracking Act (MWTA) in 1988, which was subsequently signed into Federal law on 1 November 1988 and was codified as 42 U.S.C. 6992 et seq. The MWTA amended the Resource Conservation and Recovery Act (RCRA) by adding Subtitle J to RCRA.

Many Federal and State activities have taken place since the enactment of MWTA. This paper will present an overall review of the state-of-the-art knowledge on the management of medical waste, particularly in the area of medical waste incineration since 1988. The main subjects covered in this paper are as follows:

- Regulatory framework;
- Federal (EPA) activities;
- Medical waste characteristics;
- Medical waste management and disposal options (treatment technologies) with primary emphasis on incineration;
- Health implications of managing medical waste; and
- Medical waste disposal issues.

2. Regulatory framework

2.1. Waste categories and regulatory frame work

The overriding characteristic of medical waste is its heterogeneity. A sample of medical waste can contain paper, plastics, food wastes, pathological wastes, animal carcasses, blood soaked-bandages, intravenous bags and many other types of materials. The authors grouped the medical waste into four major categories. Table 1 shows the four categories and their corresponding regulatory framework.

2.2. Medical waste tracking act

The main objective of the MWTA was to establish a two-year Demonstration Program (22 June 1989–22 June 1991) in the five covered States including three mandated States (Connecticut, New Jersey, and New York) and two 'opt-in' States (Rhode Island and Puerto Rico). The function of the Demonstration Program

Table 1
Medical waste categories and regulatory framework

Waste category	Regulatory framework
1. Regulated medical waste	MWTA, States and EPA Guidelines [1] RCRA (40 CFR 240.101)
2. Non-regulated medical waste	States
3. Hazardous waste	RCRA (40 CFR 260-265 and 122-124) and States
4. Radioactive waste	NRC Standards (10 CFR 20)

Legend: CAA: Clean Air Act; CFR: Code of Federal Regulations; MWTA: Medical Waste Tracking Act; NRC: Nuclear Regulatory Commission; RCRA: Resource Conservation and Recovery Act; States: State regulations.

Note: If any of the above waste uses incineration as the disposal means, it must be subject to the existing source or NSPS (New Source Performance Standards) requirements of the CAA.

was to track the regulated medical waste from the point of generation to the point of disposal and to establish requirements for the segregation, handling, and labeling of the medical wastes. The purpose of the Demonstration Program was to provide the Congress with information to develop proper environmental laws for future national application. Under the Act, both the EPA and the Agency for Toxic Substances and Disease Registry (ATSDR) shared the required responsibilities.

2.2.1. EPA's main responsibility

- Under Section 11002, EPA was required to promulgate regulations by 1 May 1989, listing the types of medical wastes required to be tracked in the Demonstration Program.
- Under Section 11003, EPA was required to promulgate regulations by 1 May 1989, for segregation, packaging, labeling, and tracking those designated medical wastes. EPA met these statutory requirements (Sections 11002 and 11003) by issuing regulations in the Federal Register on 24 March 1989 (54 FR 12326). The regulations, found at 40 CFR Part 259, list the medical wastes required to be tracked. These wastes are a subset of medical waste, and are defined as 'regulated medical waste' at 40 CFR 259.30.
- Under Section 11004, enforce regulations developed under the MWTA authority.
- Under Section 11008, submit a series of reports to Congress on a number of topics related to the implementation of the MWTA.

2.2.2. ATSDR's main responsibility

Under Section 11009, ATSDR was required to submit to Congress information addressing the health effects of medical waste. ATSDR met the requirement by submitting a report to Congress in September 1990 entitled 'The Public Health Implications of Medical Waste: A Report to Congress'. As required by the MWTA, the report covered the following four major areas [2]:

- A description of the potential for infection or injury from the segregation, handling, storage, treatment, or disposal of medical wastes.

- An estimate of the number of people injured or infected annually by sharps, and the nature and seriousness of those injuries or infections. ['Sharps' are needles, scalpel blades, etc.]
- An estimate of the number of people infected annually by other means related to waste segregation, handling, storage, treatment, or disposal, and the nature and seriousness of those infections.
- For diseases possibly spread by medical waste, including Acquired Immune Deficiency Syndrome (AIDS) and hepatitis B, an estimate of what percentage of the total number of cases nationally may be traceable to medical wastes.

2.3. Clean air act (CAA)

In addition to the above MWTA requirements, under Sections 111(b) and 111(d) of CAA, EPA's Office of Air Quality Planning and Standards (OAQPS) is in the process of developing emissions standards for new and existing medical waste incinerators respectively. The target pollutants to be regulated include particulate matter, acid gases, trace metals, pathogens, carbon monoxide and organics such as dioxins and furans (PCDDs and PCDFs). EPA anticipated proposal of the regulations of the New Source Performance Standards in February 1995 [3].

2.4. State regulations

With Federal regulatory activity just beginning, State requirements are of primary concern. Currently, State regulations vary significantly. Some States do not have specific medical waste incineration regulations while others impose emission limits which are more strict than those imposed on incinerators burning other types of waste. As shown in Table 2, four different States have four different standards [4, 5]. The variation in State regulatory activities is worthy of Federal attention for at least two reasons. First, strict regulations in one State may encourage the shipment of waste to other States with less stringent regulations. Second, many States, in the absence of Federal guidance, apparently are 'leap-frogging' one another to adopt the most stringent regulations [6].

3. Federal (EPA) activities

3.1. EPA's office of research and development (ORD)

To support EPA and the States in implementing the MWTA, EPA's Risk Reduction Engineering Laboratory (RREL) established a three-year cooperative effort with the California Air Resources Board (CARB) in 1989. The purpose of the cooperative effort was to conduct various studies relative to the treatment and disposal of medical waste. Under the joint effort, seven documents have been prepared, they are:

- State-of-the-Art Assessment of Medical Waste Thermal Treatment [4];
- Four Medical Waste Workshop Reports; and

Table 2
Example state medical waste incineration standards

State	PM (gr/dscf)[a]	HCl	Temp/time[b] (°F/s)	CO (ppm)	Other
NY	0.03	90% reduction	1800/1	Yes	Opacity
MD	0.1		1800/2		Opacity
OH	0.2 lb/100 lb waste	< 4 lb/h	1600/1		Opacity
WA	0.02–0.03	< 50 ppm	1800/1		SO_2

[a] PM = particulate matter (1 gr/dscf = 2.29 g/dncm).
[b] Secondary chamber exit temperature required and secondary chamber residence time required (°F/s).

- Two support documents aimed at assisting CARB in developing medical waste incineration standards for the State of California.

3.2. *EPA's office of solid waste (OSW)*

OSW was responsible for implementing the MWTA in accordance with the requirements mandated by Congress. OSW's major activities included [7]:
- Medical waste characterization study and related medical waste characterization efforts;
- Medical waste handling methods;
- Treatment technology testing;
- Medical waste health assessments;
- Medical waste grants;
- Economic analysis;
- Model State Guidelines project; and
- Co-sponsoring along with EPA's RREL and the CARB the Fourth Medical Waste Workshop.

3.3. *EPA's office of air quality planning and standards (OAQPS)*

OAQPS is responsible for applying the CAA standards to the incineration of medical waste. OAQPS's major activities included [7]:
- Testing seven medical waste incinerator sites including two sites which encompassed joint testing with the State of Michigan;
- Evaluating the performance of add-on controls including: (1) wet scrubber; (2) dry injection/baghouse; and (3) wet scrubber/baghouse; and
- Examining the performance of the combination of combustion controls (incinerator controls) and add-on controls.

4. Medical waste characteristics

Understanding the term 'medical waste' needs to begin with its statutory or regulatory definition. The Resource Conservation and Recovery Act (RCRA) now

divides solid waste into three major categories; namely: (1) hazardous waste under Subtitle C; (2) municipal waste under Subtitle D; and (3) medical waste under Subtitle J.

4.1. Solid waste

Under Section 1004 of the Solid Waste Disposal Act (SWDA) of 1965 [later to become known as the Resource Conservation and Recovery Act (RCRA), because the SWDA was amended by RCRA in 1976], solid waste is defined as follows:

> Any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agriculture operations, and from community activities, but does not include solid or dissolved material in domestic sewage, or solid or dissolved materials in irrigation return flows or industrial discharges which are point sources subject to permits under Section 402 of the Federal Water Pollution Control Act, as amended, or source, special nuclear, or byproduct material as defined by the Atomic Energy Act of 1954, as amended (in RCRA, Section 1004).

4.2. Hazardous waste

Hazardous waste is a subset of solid waste and is defined as any solid waste, or combination of solid waste, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may:

(1) cause, or significantly contribute to, an increase in mortality or an increase in serious irreversible, or incapacitating reversible illness; or
(2) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed [8].

4.3. Municipal waste

Municipal waste is a subset of solid waste and is defined as any solid waste generated at residences, commercial establishments, and institutions. It excludes construction or demolition debris and automobile scraps. In practice, specific definitions vary across jurisdictions [8].

4.4. Medical waste

Medical waste is a subset of solid waste and is defined as any solid waste which is generated in the diagnosis, treatment (e.g., provision of medical services), or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biologicals [8].

Table 3
Regulated medical waste [8]

Waste class	Waste description
(1) Cultures and stocks	Cultures and stocks of infectious agents and associated biologicals, including: cultures from medical and pathological laboratories; cultures and stocks of infectious agents from research and industrial laboratories; wastes from the production of biologicals; discarded live and attenuated vaccines; and culture dishes and devices used to transfer, inoculate, and mix cultures.
(2) Pathological wastes	Human pathological wastes, including tissues, organs, and body parts and body fluids that are removed during surgery or autopsy, or other medical procedures, and specimens of body fluids and their containers.
(3) Human blood and blood products	(1) Liquid waste human blood; (2) products of blood; (3) items saturated and/or dripping with human blood; or (4) items that were saturated and/or dripping with human blood that are now caked with dried human blood; including serum, plasma, and other blood components, and their containers, which were used or intended for use in either patient care, testing and laboratory analysis or the development of pharmaceuticals. Intravenous bags are also included in this category.
(4) Sharps	Sharps that have been used in animal or human patient care or treatment or in medical, research, or industrial laboratories, including hypodermic needles, syringes (with or without the attached needle), pasteur pipettes, scalpel blades, blood vials, needles with attached tubing, and culture dishes (regardless of presence of infectious agents). Also included are other types of broken or unbroken glassware that were in contact with infectious agents, such as used slides and cover slips.
(5) Animal waste	Contaminated animal carcasses, body parts, and bedding of animals that were known to have been exposed to infectious agents during research (including research in veterinary hospitals), production of biologicals, or testing of pharmaceuticals.
(6) Isolation wastes	Biological waste and discarded materials contaminated with blood, excretion, exudates, or secretions from humans who are isolated to protect others from certain highly communicable diseases, or isolated animals known to be infected with highly communicable diseases.
(7) Unused sharps	The following unused, discarded sharps: hypodermic needles, suture needles, syringes, and scalpel blades.

4.5. Regulated medical waste (RMW)

Regulated medical waste is a subset of medical waste and is defined as any medical waste which was tracked under MWTA's Demonstration Program. Specifically, RMW covers seven categories and they are listed in Table 3.

4.6. Medical waste versus infectious waste

Traditionally, the term 'medical waste' is often used interchangeably with the term 'infectious waste'. Under the MWTA regulations, EPA did not provide the

regulatory definition of 'infectious waste'. However, EPA defined infectious waste in the following manner (quoted from 40 CFR 240.101, 1986 edition):

> Infectious waste means: (1) equipment, instruments, utensils, and fomites of a disposable nature from the rooms of patients who are suspected to have or have been diagnosed as having a communicable disease and must, therefore, be isolated as required by public health agencies; (2) laboratory wastes such as pathological specimens (e.g., all tissues, specimens of blood elements, excreta, and secretions obtained from patients or laboratory animals) and disposable fomites (any substance that may harbor or transmit pathogenic organisms) attendant thereto; (3) surgical operating room pathologic specimens and disposable fomites attendant thereto and similar disposable materials from out-patient areas and emergency rooms.

For a waste to be infectious, it must contain pathogens with sufficient virulence and quantity so that exposure to the waste by a susceptible host could result in an infectious disease.

4.7. Infectious waste

According to a 1988 survey of over 400 US hospitals, more than 90% of hospitals considered blood, sharps, wastes from the hospital centers of microbiology, communicable disease, pathology, and autopsy, and contaminated animal carcass waste as infectious and more than 80% considered surgical dialysis, and laboratory waste as also infectious [9].

4.8. Quantity generated

Since the enactment of the MWTA, EPA has been using the term regulated medical waste (RMW), instead of infectious waste, to control the disposal of medical waste generated from various sources. A 1990 EPA Report to Congress, 'Medical Waste Management in the United States', indicated that each year approximately 456,000 t of RMW are produced in the United States by about 375,000 generators [10]. The vast majority of the RMW (about 77%) is generated by hospitals, which comprise less than 2% of the total number of generators. The remainder is produced by a large, diverse group of generators including laboratories, physicians' offices, veterinarians, etc. The majority of these generators produce relatively small quantities (less than 50 pounds per month) of RMW.

A summary of the type and numbers of medical waste generators and the approximate quantity of the RMW generated by each type in the United States is presented in Table 4 [10].

4.9. Heating value

The heating value of a waste is a measure of the energy released when the waste is incinerated. It is measured in units of Btu/lb (1 Btu/lb = 2.324 J/g). In general, a heating value of about 5000 Btu/lb (12,000 J/g) or greater is needed to sustain

Table 4
Sources and quantities of regulated medical waste

Generator type	Numbers of generators	RMW generated all facilities (t/yr)	RMW generated per facility (lbs/month)
1. Hospitals	7100	359,000	8400
2. Laboratories	4300	15,400	600
3. Clinics	15,500	16,700	180
4. Physicians' offices	180,000	16,400	24
5. Dentists' offices	98,400	7600	13
6. Veterinarians	38,000	4600	20
7. Long-term health care facilities	12,700	29,600	390
8. Free-standing blood banks	900	2400	440
9. Funeral homes	20,400	3900	32
Total	377,300	455,600	

Table 5
Properties of medical waste components

	HHV (Btu/lb)	Density (lb/ft^3)	Moisture (Wt%)	Heat value, as fired (Btu/lb)
Human anatomical	8000–12,000	50–75	70–90	800–3600
Plastics	14,000–20,000	5–144	0–1	13,900–20,000
Swabs, absorbents	8000–12,000	5–62	0–30	5600–12,000
Alcohol, disinfectants	11,000–14,000	48–62	0–0.2	11,000–14,000
Animal infected anatomical	9000–16,000	30–80	60–90	900–6400
Glass	0	175–225	0	0
Beddings, shavings, paper and fecal matter	8000–9000	20–45	10–50	4000–8100
Gauze, pads, swabs, garments, paper, cellulose	8000–12,000	5–62	0–30	5600–12,000
Plastics, syringes	9700–20,000	5–144	0–1	9600–20,000
Sharps, needles	60	450–500	1	60
Fluids, residuals	0–10,000	62–63	80–100	0–2000

combustion. Wastes with lower heating values can be burned, but they will not maintain adequate temperature without the addition of auxiliary fuel. Table 5 lists typical heating values and moisture contents of various components of medical wastes [5]. If incineration is to be used as the treatment method, these values illustrate the range of properties that may be in the incinerator at any given time. Incinerator designs must not only account for the average heating value of the waste, but must also consider the possible variations in heating value.

4.10. Microbial composition

Several studies reported the microbial composition of medical waste. The most extensive of these studies examined the microbial composition of hospital waste,

municipal waste, and sewage sludge [11]. The study showed that all three solid wastes had a similar concentration of fecal-indicator bacteria, although a greater proportion of bacteria in the municipal solid waste was apparently of non-human origin. Several specific pathogens were also identified in each waste, including eight in the hospital waste, ten in the municipal waste and six in the sewage sludge. However, detailed characterizations of all pathogenic organisms in the various categories of medical or infectious waste have not been completed [9].

5. Medical waste management options

5.1. Variation of medical waste

There is a large variation in the properties of medical wastes. Materials range from pure paper to food products to pathological waste. These variations have a dramatic impact on the performance of medical waste treatment equipment.

5.2. Pollution prevention

The best medical waste management technique for medical institutions is to minimize the generation of waste. However, only a certain level of reduction can be achieved due to the nature of the waste stream and its generation process.

5.3. Disposal technology

Preliminary results of a survey of 200 acute-care hospitals across the US in July of 1987 showed that:

- Seventy percent (70%) of the responding hospitals either owned or shared an incinerator for waste disposal;
- Forty-nine percent (49%) of the hospitals used steam sterilization;
- Eleven percent (11%) of the hospitals disposed of infectious waste in a sanitary landfill without prior sterilization;
- Twenty-three percent (23%) of the hospitals disposed of blood or blood products to a sanitary sewer;
- Twenty-one percent (21%) disposed of dialysis wastes to a sanitary sewer; and
- Fourteen percent (14%) of the hospitals ground-up infectious wastes and discharged them to the sewer.

The other disposal option for most hospitals is to pay a licensed transporter and disposal contractor to take the waste. This option is significantly more expensive than onsite disposal practices and increases the liability of the medical institution [9].

5.4. Source separation

Source separation refers to both the segregation of infectious and non-infectious wastes and the removal of specific compounds from the waste stream prior to

incineration. It is estimated that about 85% of hospital waste can be categorized as general refuse, while the remaining 15% is contaminated with infectious agents. Thus, segregation of medical waste at the point of generation can reduce the volume of infectious waste significantly [12].

6. Medical waste incineration

EPA's research data and industry's operating experience indicate that incineration is currently one of the best available technologies for disposing of various waste streams [13]. Incineration has historically been the most widely used treatment technology for the disposal of medical waste and has the potential to continue to be an important waste disposal option. The major advantage of incineration is that it significantly reduces the volume of material, can destroy pathogens and hazardous organics, and renders the waste unrecognizable, and in the form of ash. The disadvantage is that incineration may emit trace amounts of unwanted pollutants such as the polychlorinated dioxins and furans (PCDD and PCDF) and metal particulates if incinerators are not well designed and operated. In particular, emissions from on-site hospital waste incinerators require special attention, due primarily to the typical hospital's proximity to cities [8].

According to the American Health Association in 1983, about 70% of medical waste was incinerated onsite, 15% autoclaved, and 15% treated offsite [14]. If one included the waste incinerated in off-site treatment, incineration treated more than 80% of the US's medical waste. Consequently, this paper focuses on the detailed review of issues related to medical waste incineration.

There are two major types of incinerators used for the treatment of medical waste in the United States and Canada:

(1) Modular incineration which are of two varieties: Starved air incinerators, and Excess air incinerators.

(2) Rotary kilns which generally comprise two combustion chambers and air pollution control equipment.

6.1. Types of medical waste incinerators

6.1.1. Starved air incinerators

As the term implies, 'starved air' incinerators make use of the starved air combustion process. When less than the required (stoichiometric) amount of air or oxygen is provided for combustion of organic waste, the waste will smolder, generating a smoke (off-gas) rich in organics. If air is injected into this hot, combustible gas stream, the stream will self-combust, and the entrained organic components will burn. The starved air incinerator, shown in Fig. 1, includes two furnace chambers [15]. In the primary combustion chamber, the waste is fired with less than the stoichiometric air requirement. The off-gas is burned out in the secondary combustion chamber, where from 100% to 140% of the stoichiometric air requirement is injected. At least one burner is required in the primary chamber to bring the temperature of the

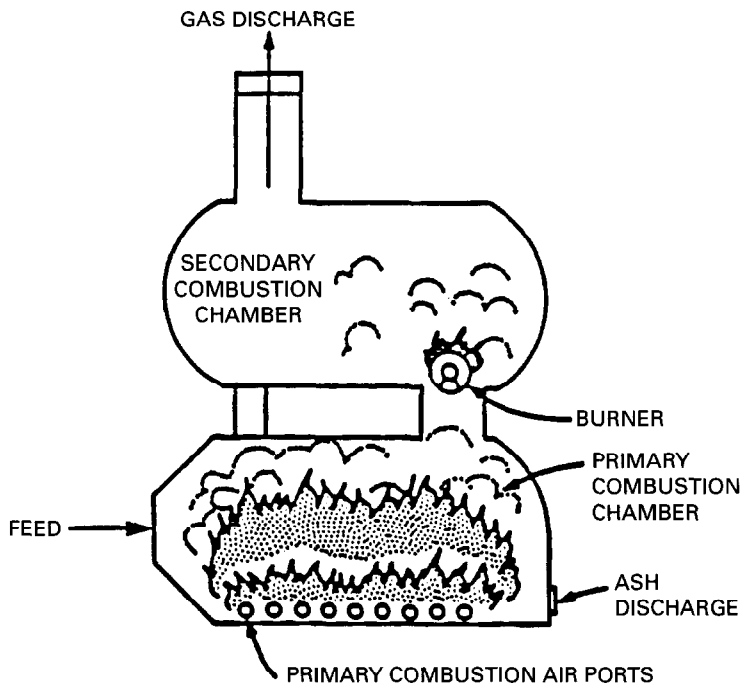

Fig. 1. Starved air incinerator.

chamber to the required operating temperature. Enough air is injected into the chamber, usually from 40% to 60% of the stoichiometric requirement, to allow sufficient burning to generate the heat required by this process. Usually a primary chamber combustion air fan is provided to supply this air flow. Another fan, the secondary chamber air supply fan, is normally provided as a source of air for the secondary combustion chamber. A burner is provided to ensure burning in the secondary combustion chamber, and this burner is normally always firing, to ensure the maintenance of a flame in the chamber under any and all conditions of feed and operation.

The injection into the primary combustion chamber of only a fraction of the air required for full burnout produces relatively little carry-over of particulate from the primary chamber. The higher the air flow into and around the waste, the higher the entrained particulate carry-over; the reduction of this carry-over is an important feature of this system. Another feature of the starved air system is its control of chamber temperature. When the waste is burning with the stoichiometric air (or oxygen) requirement, a maximum temperature will be reached. When the waste is fired with greater air flow than the stoichiometric requirement, the excess air will cool the gas stream. When the waste is fired with less than the stoichiometric air requirement, there will be insufficient air to burn out all of the organics in the waste. When the primary unit approaches the stoichiometric mode (from sub-stoichiometric), the greater the air supply, the higher the temperature, because as more air is injected into the process, more heat is released.

Starved air furnaces are used as batch units or as either semi-automated or continuously operating systems. In the batch unit mode, waste is charged and allowed to burn out before another charge is inserted. Semi-continuous operation utilizes a charging ram which may be cycled a number of times in a day's operation, but which may not have automatic ash removal and must be cleaned out daily.

In the continuous mode of operation, fired waste is loaded into the charging hopper from two to six times per hour. A charging ram loads the waste into the furnace and as the waste enters the furnace chamber, it pushes material that has been previously charged towards the chamber exit. Ash removal is automated in this type of system. The majority of starved air incinerators in use today for medical waste applications are of the semi-continuous type [4, 16].

Starved air incinerators come in all sizes and shapes. Incinerators are available with design capacities ranging from 50 lb/h (23 kg/h) to 4000 lb/h (1800 kg/h). Some are manually controlled, and others are automatically controlled. Some use manual waste loading and ash removal, and others are fully automated.

6.1.2. Excess air incinerators

A typical modular incinerator, commonly termed a 'retort or batch incinerator', is shown in Fig. 2 [15]. In this type of unit, waste is fired in the primary chamber. The secondary combustion chamber provides the residence time, temperature, and supplemental fuel for combustion of the unburned organic carried over from the primary chamber. The incinerator is a compact furnace in the form of a cube with multiple internal baffles. The baffles are positioned to guide the combustion gases through 90° turns in both lateral (horizontal) and vertical directions. At each

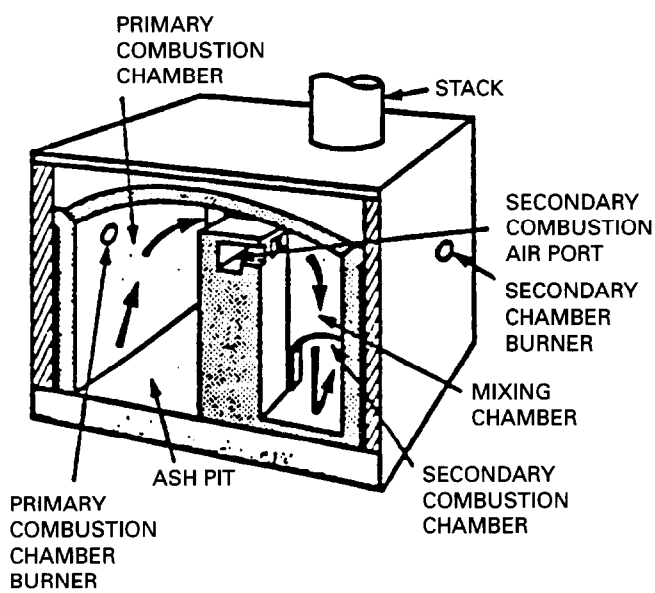

Fig. 2. Excess air incinerator.

turn, ash (soot) drops out of the flue gas stream. The waste is charged on a batch basis and is allowed to burn out over a period of hours. A typical operation includes charging at the end of the day, waste firing, and burnout by morning. The ash residual is cleaned out of the incinerator prior to each day's charging. As the name implies, an excess air incinerator is operated with excess air levels well above stoichiometric (typically 60–200% excess air) in both chambers.

Air is injected into the primary and secondary combustion chambers through the supplementary fuel burners. Each chamber normally has one or two burners to provide the heat required to bring the furnace up to operating temperatures and to maintain its required operating temperature. The excess air incinerator is not easily adaptable to automatic or continuous operation [16].

6.1.3. Rotary kilns

The rotary kiln (Fig. 3) is a horizontal refractory-lined cylinder that rotates about its horizontal axis [16]. Waste is charged directly into the kiln. The rate of waste flow through the kiln is a function of the speed of the kiln, which is variable, and the rake, or angle of the kiln to the horizontal, which is normally fixed. Air typically in excess of the stoichiometric requirement is provided to the kiln to help burn out the waste. A secondary combustion chamber is part of the kiln system. Off-gas from the kiln contains volatiles from the waste that have not burned out, and burnout is completed in the secondary chamber. The waste is agitated in the kiln by the rotating motion of the kiln, normally in the range of 1–3 rpm. As the waste is subjected to

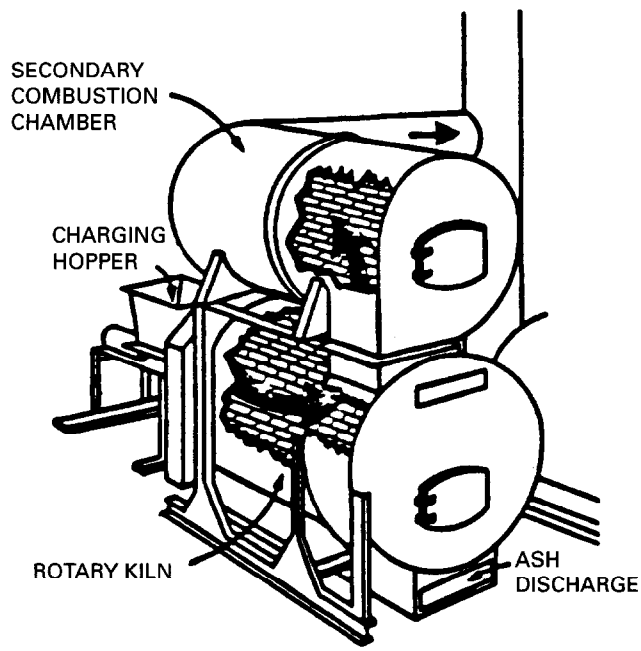

Fig. 3. Rotary kiln.

this turbulence, it is contacted by air and thus combustion is encouraged. This turbulence, however, increases the particulate load in the flue off-gases. The kiln system generally requires more extensive air emission control than the modular units. The kiln system is a continuous system, i.e., waste is continually fed to the unit, normally with a charging ram. By the time the charge reaches the end of the kiln, it has burned out to an ash which can be discharged dry or into a water quench [16].

The combination of a kiln plus secondary burner equals the full-load rating (usually expressed in the units of millions at Btu's per hour) of the incineration system [5].

About twenty different manufacturers that could provide the incinerators in sizes varying from less than 45 kg/h (100 lb/h) to over 3600 kg/h (8000 lb/h) were identified. The design practices for these units vary somewhat from manufacturer to manufacturer [4].

The performance of medical waste incinerators has not been critically evaluated. Generally speaking, a majority of medical waste incinerators do not have air pollution control equipment. Consequently, they (in particular, those incinerators installed in the 1960s) may emit harmful pollutants [4].

Incineration technologies currently offered will be severely challenged if comprehensive and stringent performance criteria (such as those recently proposed by California and New York) are placed on them. In particular, their ability to meet stringent environmental requirements such as limits on PCDD/PCDF emissions, metal emissions, pathogen destruction and acid gas control in a cost-effective manner has not yet been demonstrated [4].

6.2. Air pollution control equipment (APCE)

To date, only a few (<1% in California) medical waste thermal treatment facilities include APCE in their facilities. The majority of those that do have APCE have wet scrubbing technologies such as the venturi scrubber. This selection is based largely on economics, ease of operation and emissions limits. These types of scrubbing technologies have been successfully applied to medical waste incinerators. However, it is difficult to achieve high levels of particulate control using this technology. Thus, stringent particle control, or metals or HCl emission standards may require use of alternative technology such as spray dryers/fabric filters which have been successfully applied to municipal solid waste systems to achieve high levels of acid gas removal and particulate and PCDD/PCDF (dioxins/furan) control. However, spray dryer/fabric filter systems are not currently cost-competitive with wet scrubber systems. A fabric filter system was found to have excellent performance on all metals tested. More stringent regulations may favor spray dryer/fabric filter systems in the future [4].

6.2.1. Dry scrubber

A dry scrubber utilizes absorption and adsorption for the removal of acid gases, primarily hydrogen chloride, sulfur dioxide and hydrogen fluoride. The scrubbers can be grouped into three major categories: (1) spray dryer absorbers; (2) dry

injection adsorption systems; and (3) combination spray dryer and dry injection systems. The main differences between the various systems are the physical form of the alkaline reagent and the design of the vessel used for contacting the acid gas-laden stream [8].

6.2.2. Wet scrubber (absorber)

A wet scrubber is a device which uses a liquid to clean a gas stream. The pollutants controlled by wet scrubbers include particulate matter and the acid gases (HCl and SO_2). The device uses a variety of methods to wet the contaminant particles and then impinge the wetted and unwetted particles on collecting surfaces followed by their removal from the surfaces by a flush with a liquid. It can handle hot gases containing sticky particulates and droplets. Scrubbers, which remove gases by absorption, remove particulate matter mainly by inertial impaction and are generally effective for particles larger than 0.5 μm in size. Smaller particles require much higher pressure drops. Scrubbers can reportedly be effective for particles less than 0.1 μm if pressure drops of 40–50 in. of water are utilized. Types of wet scrubbers include [8]:

- Cyclone type scrubber;
- Fume scrubber;
- Ionizing wet scrubber;
- Mechanical scrubber;
- Orifice-type scrubber;
- Packed tower (packed-bed scrubber);
- Plate scrubber;
- Spray chamber (spray tower);
- Venturi scrubber; and
- Wet filter.

6.2.3. Baghouse (bag filter or fabric filter)

A baghouse which is especially effective at removing fine particulate matter is much like a home vacuum cleaner bag. The bag removes solid particulate matter from the flue gas stream by filtering the flue gas through fabric bags, usually made of cloth or glass fibers. Small particles are initially captured and retained on the fibers of the cloth by means of interception, impingement, diffusion, gravitational settling, and electrostatic attraction. Once a mat or cake of dust is accumulated, further collection is accomplished by sieving or other mechanisms. The cloth then serves mainly as a supporting structure for the dust mat responsible for the high collection efficiency. Periodically, the accumulated dust is removed for disposal [8].

6.2.4. Electrostatic precipitator (ESP)

ESPs are used to remove particulate matter from flue gas streams. Particulate matter is first charged with electricity before it can be collected in an ESP. Once the particles or liquid aerosols that makeup the particulate matter are charged, they move toward an oppositely charged surface because of electrostatic attraction (opposite charges attract each other, the similar charges repel each other). The collected

particles are removed by rapping or washing the collecting surface. This charging, collecting, and removal process is commonly referred to as precipitation. ESPs can be classified according to a number of design features. These features include the method of charging (single-stage or two-stage), the method of particle removal from collection surfaces (wet or dry), the temperature of operation (cold-side or hot-side), and the structural design and operation of the discharge electrodes (tubular or plate) [8].

6.3. APCE cost

The cost of APCE systems can be a significant if not the dominant cost element in the overall system. For example, the cost of the starved-air combustion systems, based upon vendor data, was found to vary directly with the size of the equipment. For the larger quantities of waste, rotary kilns were found to be competitive with starved-air systems. A venturi scrubber/acid gas absorber for a 454 kg/h (1000 lb/h) incinerator was estimated to cost $200,000. In addition, the operation and maintenance costs could be nearly $90,000 for the first year for this same system. A spray dryer/fabric filter system may cost as much as $800,000 for a similar-sized facility. However, the cost of spray dryer/fabric filter systems does not increase as rapidly with unit size as venturi scrubber/acid gas absorber systems do. Thus, spray dryer/fabric filters are more competitive for larger facilities [4].

6.4. Potential incineration emissions

6.4.1. Air emissions

Medical waste incinerators can emit toxic air pollutants, if the incinerators are not properly designed or operated. The pollutants include:

- Particulate matter;
- Acid gases;
- Trace metals;
- Products of incomplete combustion; and
- Polynuclear organic matter (including dioxins and furans, PCDD and PCDF).

The major concern, of course, centers around the emission of dioxins and furans. The California Air Resources Board (CARB) initiated a task in 1986 to test the dioxin and furan emissions from two hospital waste incinerators and published two separate reports in January and April 1987. Table 6 summarizes the results of dioxin and furan emissions data available from CARB and Canada for hospital waste incinerators [17–19]. For comparison, selected data are included for a range of municipal solid waste incinerators [16] and other combustion sources investigated in the EPA's Tier IV study [20]. The emissions of the three hospital waste incinerators are remarkably high in comparison with these other sources. This fact is especially obvious when compared on an emission basis normalized by the amount of waste burned. On this basis, only the poorest municipal solid waste (MSW) incinerator (Hampton, which at one time was shut down due to excessive emissions) has comparable PCDD/PCDF emissions. Also, only the worst Tier IV source had higher emissions.

Table 6
Dioxin/furan emissions summary

	PCDD		PCDF	
	(μg/Mg)	(ng/Nm^3)	(μg/Mg)	(ng/Nm^3)
Hospital waste incinerators				
Cedar Sinai [18]	1986	160–260	5384	386–700
Saint Agnes [17]	6272	290–450	10961	700–785
Royal Jubilee [19]	1625–2680	117–197	715–1115	52–84
Municipal waste incinerators [16]				
Hampton	1000–27000	243–10700	1770–41200	400–37500
North Andover		225		323
Marion County	5.2	1.13	1.9	
Prince Edward Island	200–500	60–125	300–500	100–160
Tulsa	74.5	18.9	61.1	15.5
Wurzburg	62.7	22.1	79.2	27.9
Akron	636	258	1680	679
Tier IV sources [20]				
Black liquor		2–17		1.5–45
Wood fired boiler		102		154
Carbon red furnace		28.8		
Sewage sludge		114		
Drum and barrel		687		

Note: μg/Mg = microgram PCDD/megagram of waste incinerated; ng/Nm^3 = nanogram/normal cubic meter.

The emissions from the modern mass burn technology (Marion County, Tulsa and Wurzburg) are on the order of 30 times less than the emissions from the hospital waste incinerators that had been tested. For modern MSW systems equipped with advanced air pollution control devices, the emissions are as much as three orders of magnitude lower (compare Marion County with St. Agnes). Thus, because PCDD/PCDF emissions are of sufficient concern to convince the EPA to regulate MSW combustion systems, emissions from hospital waste incinerators should also be considered to be of significant importance (and, of course, they are important, witness EPA's recent proposal of new regulations for these incinerators [3]).

Four mechanisms of PCDD/PCDF formation/emissions were hypothesized [4]:

- Poor destruction of PCDD/PCDF in the waste;
- Incomplete destruction of long-chain organics which convert to PCDD/PCDF;
- Formation from precursors; and
- Low-temperature catalyzed reactions.

The database is currently insufficient to evaluate which of these mechanisms is most important. However, the emissions data did correlate with entrained particulate matter from the combustion device suggesting the importance of particle precursors. Based on analogies with hazardous waste, municipal solid waste and analysis of the special features of medical waste incinerators, the parameters expected to impact PCDD/PCDF emissions from medical waste incinerators are as follows [4]:

- Primary zone gas velocities which influence particle entrainment;
- Primary zone combustion air flow which determines gas velocity and stoichiometry;
- Secondary zone temperature which determines the organic destruction level;
- Uniformity of temperature (both spatial and temporal) in the secondary zone;
- Particle holdup at temperatures found to favor PCDD/PCDF formation (480–660 °F);
- Temperature of the particle control device which determines condensation of PCDD/PCDF on particles; and
- Fine particle control which determines the amount of PCDD/PCDF on particles that are removed from the flue gas.

6.4.2. Toxic and carcinogenic metals

The dominant emissions from medical waste incinerators include arsenic, lead, cadmium, and chromium. In general, the uncontrolled emissions (either without or before APCE) of these metals is substantially less for medical waste incinerators than for municipal solid waste systems. This is either due to a lower concentration of these metals in medical waste or due to combustion conditions in medical waste incinerators which are less likely to drive metals out of the solids. A comparison of starved-air systems burning either medical waste or municipal waste indicates that lower metals escape medical waste systems suggesting that medical waste likely contains less of these metals [4].

At the conditions in the primary zone of starved-air systems, arsenic, cadmium and lead are probably volatile while chromium is likely to remain as a solid. Over the range of typical conditions, this phenomenon should not change. The emission of the volatile species from uncontrolled incinerators will be dictated by the amount of these metals in the waste stream. Virtually all the volatile metals are released from the solid. These metals are expected to form fine aerosols as they recondense. Fine particle capture combined with flue gas cooling may be necessary to achieve high capture levels. For chromium, which is not expected to be volatile except at higher temperatures, the combustion conditions are more important. Chromium escapes primarily by entrainment which is influenced by the primary zone gas velocity and the characteristic size of the chromium in the waste. Once out of the primary chamber, chromium should be easier to capture due to the larger particle sizes. However, larger fractions of chromium volatilize at high temperatures when chlorine is present. Under those conditions, chromium is expected to behave more like volatile metals [4].

6.4.3. Pathogens

The pathogens present in infectious waste are a complex mixture of bacteria, mycobacteria, fungi, parasites, viruses and rickettsia. At the severe conditions that exist within incinerators, pathogenic organisms are very fragile and easy to destroy. The tests conducted to date on operating incinerators have indicated that pathogens do not survive except at low temperatures (1100 °F). However, there is some evidence that pathogens from the environment around the incinerator can get into the stack. These pathogens can bypass the combustion zone and are thus not destroyed.

The pathogens are probably released into the air as wastes are handled in the area around the incinerator. The control of pathogen emissions appears to be similar to the minimization of trace organics emissions. In addition, however, care must be taken to ensure that all fugitive gases enter the incineration system and pass through the combustion zone [4].

6.4.4. Cytotoxic compounds

Cytotoxic compounds are substances generally used in chemotherapy that are highly toxic to cells. Because of the acute nature of the hazards associated with these compounds, the goal is complete destruction. No data on emissions of cytotoxic compounds are currently available. Since these compounds are organic, the control techniques should be similar to those for both trace organics and pathogens. The temperature required to destroy cytotoxic compounds with high efficiency has been estimated to be 1650 °F. This estimate is based on consideration of thermal decomposition of the more refractory compounds [4].

6.4.5. Acid gases

Three species were considered acid gases: nitrogen oxides, sulfur oxides and hydrogen chloride. Medical waste typically contains 0.2% sulfur, 4% chlorine and 0.5% nitrogen. Substantial portions of sulfur and chlorine are converted to SO_2 and HCl respectively, without significant dependence on combustion conditions. Further control of these species must be accomplished by removal of sulfur- and chlorine-bearing constituents from the waste prior to burning or by flue gas scrubbing. The formation of NO_x is dependent upon combustion peak temperature, fuel/air mixing and primary zone stoichiometry. Gas scrubbing of NO_x is not a viable alternative because of the low solubility of these components [4].

6.4.6. Radioactive materials

Low-level radioactive materials are sometimes found in medical waste; however, radioactive emissions from general medical waste incinerators have not been measured. The radioactivity of the materials cannot be altered by incineration but the physical form can be dramatically changed. The radioactive materials behave like their non-radioactive counterparts so that the fate of the radioactivity depends on factors such as operating chamber temperature, air volume and velocity, extent of combustion, chemical and physical form of the waste and the elements involved [4].

6.5. Solid and liquid effluents

6.5.1. Solid and liquid effluents from incinerators

The quality of ash from medical waste incinerators is unknown. Judging from the nature of the medical waste, it is highly likely that the ash would contain heavy metals such as mercury from broken thermometers.

Solid and liquid effluents are also of concern. Solid effluents are composed primarily of ash from the combustor chamber of an incinerator. If the system is equipped with some type of flue gas cleaning equipment, then captured fly ash and liquid effluents may also be present. Both solid and liquid effluents may contain potentially harmful materials which are of concern to human health and the environment [4]. The harmful materials include:

6.5.1.1. Organic material. Potentially dangerous organic materials include the following three classes:

- Trace organics (PCDD/PCDF);
- Pathogens; and
- Cytotoxic materials.

Relatively high concentrations of PCDD and PCDF have been found in ash from some incinerators. However, no pathogens have been observed in ash from incinerators operated at above 1100 °F. No studies have examined the survival of cytotoxic materials in ash. Similar methods are used to ensure the destruction of all three classes of potentially dangerous organic material. Ash is retained in the combustion chamber for long periods of time. Combustion air is supplied from beneath the bed to ensure adequate amounts of oxygen are available for the complete gasification of fixed carbon. Modular starved-air incinerators and rotary kiln systems also mix the solids to break-up dense clumps which may form cold pockets [4].

6.5.1.2. Inorganic material. Potentially dangerous inorganic materials include:

- Toxic and carcinogenic metals; and
- Radioactive material.

Inorganic materials cannot be destroyed by the incineration process. Current designs focus on forcing each material into the effluent stream most easily handled. Conditions which promote retention of toxic and carcinogenic metals in the residual ash are used. This principally involves operating the primary combustion chamber at the lowest practical temperature. On the other hand, most radioactive materials are volatile and vaporize during incineration. They are diluted by combustion air and emitted to the atmosphere if not removed by effective APCE [4].

6.6. Monitoring and automatic control

It is important to make a distinction between a parameter that is monitored and a parameter that is monitored and automatically controlled. When a parameter is monitored, it means that information is obtained by a sensing device in the incinerator and the information is transmitted to a receiver such as a display meter or recorder for one to view. However, the information from the sensor does not automatically control any operations.

When a monitored parameter is used for control, the information transmitted from the sensor is used to adjust some function(s) within the incineration system that in turn controls the monitored parameter. The control system includes a controller to send a signal to the operating system which is adjusted.

Table 7
Monitor and control parameters for incinerators

Monitored/controlled parameter	Purpose	Incinerator functions controlled (when possible)
Temperatures of primary and secondary combustion chambers	Indicator of temperature operating range; control parameter	Combustion air; auxiliary burners
Draft	Indicator of pressure in chamber; control parameter	Barometric damper; ID-fan damper
Oxygen	Indicates excess air level	Combustion air
Carbon monoxide	Indicator of combustion efficiency	
Opacity	Indicator of emissions	
Charge rate	Indicator of heat input	Automatic feed; system interlock

Table 8
Monitor and control parameters for scrubbers

Monitored parameter	Scrubber functions controlled (when applicable)
Pressure and pressure drop	Venturi throat; ID fan
Scrubber liquid flow rate or pressure	Liquid flow control valve
Scrubber liquid pH	Caustic flow control valve
Inlet temperature	Emergency quench/dilution air; bypass stack prequench

Table 9
Monitor and control parameters for fabric filters

Monitored parameter	Fabric filter operating functions controlled
Pressure drop	Cleaning cycle
Inlet gas temperature	Emergency bypass stack

Typical monitoring and control parameters for general types of incinerators are listed in Table 7, for scrubbers, Table 8, and for fabric filters, Table 9 [21].

6.7. Good incineration practice

To insure the destruction of all viable microorganisms, it is necessary that not only the gas and particulate matter exiting the incinerator be subjected to adequately high temperatures for a sufficiently long time, but also that the ash residue be subjected to these conditions. A number of management practices may result in inadequate treatment including: (1) adding waste during the start-up period when the incinerator and associated ductwork are cold; (2) the incinerator is not brought up to full operating temperature before feeding each batch of waste; and (3) adding

high moisture content waste at too rapid a rate which can result in a rapid reduction in incinerator temperature [9, 4].

The application of today's leading APCEs will address not only particulate control but also acid gas control as well (dry scrubbers, fabric filters and wet scrubbers). It is likely that combustion control can reduce the emission of organics considerably but any such control is likely to increase particulate carry-over out of the furnace (because such combustion control systems tend to increase turbulence).

7. Other treatment technologies

7.1. Steam sterilizaion (autoclaving)

This method is widely used for decontamination of microbiological and other laboratory waste prior to disposal. Laboratory culture dishes and other materials are typically collected in plastic bags, then placed in a steel or polypropylene container and loaded into the autoclave. The size of the load and the material of the autoclave bag and container affect the length of time required for the waste material itself to reach the temperature required for sterilization. Recommended conditions for hospital sterilization are processing for 12 min in contact with saturated steam at 121 °C to insure 99.9999% reduction in the number of viable spores of *Bacillus stearothermophillus*. However, investigators have shown that operation of an autoclave at the recommended temperature for 15–20 min is often not sufficient to achieve decontamination. Several investigators have recommended a processing time of 45 min or longer for waste placed in an autoclave bag and steel container with water added to facilitate steam penetration [9].

7.2. Gas sterilization

Gas sterilization processes involve exposing the waste to toxic fumes. The wastes are placed in an air-tight chamber. Air is evacuated from the chamber and a toxic gas like ethylene oxide is introduced. The gas penetrates the waste and kills infectious agents. As with steam sterilization, an important consideration is the ability of the disinfecting compound to penetrate the waste. Gas sterilization is rarely used to treat medical wastes [9].

7.3. Chemical disinfection

Chemical disinfection processes involve soaking medical wastes in a liquid chemical disinfectant. The disinfectant breaks down organic materials and destroys infectious agents. The wastes are initially ground to insure that the chemical agent can penetrate the wastes and to aid in disposal of the residues. The materials then enter a bath where they are mixed with the chemical agent. Some disinfecting

chemicals such as sodium perchlorate will reportedly also breakdown glass. The resulting liquids including any remaining disinfecting agents are released to the public sewer system while the solid residues are dried and disposed of in a landfill [22].

7.4. Grinding and shredding

Grinding and shredding are used to convert medical wastes into a more homogeneous form that can be easily handled. In these processes, medical wastes are placed in a container and physically broken into smaller particles while inside the container. The container is sometimes maintained at a negative pressure to insure that no material escapes from the device. Since grinding and shredding do not affect the infectious nature of the waste, they are almost always used in conjunction with other treatment techniques (as pre-treatment processes) [22].

7.5. Thermal inactivation

Thermal inactivation involves heating a waste to temperatures which destroy infectious agents. Generally this method is used only for large volumes of liquid wastes. The wastes are placed in a chamber which is heated to a pre-determined temperature. The wastes are held in the chamber for a specified period of time and then released [1].

7.6. Irradiation

Irradiation is a technology used for treating medical wastes. The process involves using ionizing radiation from a source such as cobalt 60 to destroy infectious agents. The technique is similar to that currently being used to sterilize medical supplies, food, and other consumer products. After sterilization, the wastes are generally ground, compacted and then shipped to a landfill site [23].

7.7. Microwave treatment

Microwaves can be used to destroy infectious agents. Infectious wastes are first ground and shredded to improve the effectiveness of the treatment system. Next the wastes are sprayed with water. An auger moves the wastes past a series of microwave power packs which subject the waste to microwaves. The microwaves destroy infectious agents and heat the waste to 200 °F. Volatile materials and water are driven off during the process. The process has been found to be successful in tests conducted by European health departments [23].

7.8. Sewer disposal

Some hospitals (23%) dispose of blood and other body fluids directly to the sewer, and about 14% grind up solid infectious waste and discharge the resulting material

to a sanitary sewer system. The equipment used is similar to an in-sink home garbage grinder [9].

7.9. Landfill

Landfill disposal of infectious waste is recommended only following incineration or sterilization. Data generated in 1988 indicated that about 11% of US hospitals disposed of infectious waste directly to landfills without prior treatment [9].

8. Bacterial residue

8.1. Bacterial residue in land disposal

Several studies showed that the numbers of fecal indicator bacteria in medical waste that is land disposed or that are in leachate from this waste decline with time. Some studies have shown that fecal coliform numbers decreased to below detectable levels in the leachate from medical waste, municipal waste and sewage sludge after four months, and streptococci levels after one year. However, a study of active and inactive landfills (9 yr inactive) found that pathogenic bacterial species were detected in the leachate and solid waste in both types of landfills. In a study of municipal solid waste lysimeters seeded with human viruses, viruses were not detected in the leachate over a four-month period or in the refuse after 4–5 months of operation. These studies indicated that some pathogenic species can survive landfill conditions for several months to several years. However, medical waste does not appear to present hazards different from municipal waste and sewage sludge [9].

8.2. Bacterial residue in the marine environment

Most bacterial and viral pathogens in the marine environment are associated with suspended and bottom sediment, which apparently also increases their survival time. Coliform bacteria were present in bay sediments 4 yr after the dumping of sewage sludge. The uptake and concentration of human pathogens in fish and shellfish is well documented and is associated with numerous disease outbreaks [9].

8.3. Bacterial residue in ocean dumping

Medical waste that is dumped in the ocean may contaminate the marine environment. Human exposure to infectious agents could result from skin contact with contaminated sea water or sediment, direct contact with medical waste that has washed into bathing areas or onshore, or ingestion of contaminated seafood [9].

8.4. Bacterial transport

Although the transport and survival of pathogens is determined by a host of interrelated factors and is highly variable, viable bacteria and viruses have been found

to travel long distances in the subsurface under certain conditions. Reported survival times for some common human bacterial pathogens range from less than one day to several months. Viruses are more resistant to environmental changes and generally have a longer life span in soil than bacteria, (in general bacteria are removed from water by soil adsorption after travel through a few centimeters). Viruses, however, have been detected in ground water under a sanitary landfill at depths of 22 m and some 400 m downstream [9].

9. Health implications of managing medical waste

9.1. Health risk

9.1.1. Health risk

Several factors are necessary for the induction of an infectious disease. They are: (1) presence of a pathogen of sufficient virulence; (2) presence of the pathogen in quantity sufficient to cause disease; (3) existence of a route of exposure to the pathogen; and (4) the resistance of the human host. The health risk attributable to medical waste is difficult to quantify in the absence of information on the presence of specific pathogens in the waste, the dose-response relationships or threshold values for the health effects associated with these various pathogens, and specific scenarios concerning exposures to these pathogens [9].

9.1.2. Infective dose

The infective dose is the number of microorganisms required to produce infection in humans. A great deal of uncertainty is associated with infective dose estimates, due to the variable contribution of a number of factors, including host sensitivity, pathogen virulence, assay technique, etc. [9].

9.2. Public health implications of medical waste

As required by the MWTA, ATSDR conducted a study on public health implications of medical waste and have reached the following main conclusions [2]:

(1) The general public's health is not likely to be adversely affected by medical waste generated in the traditional health care setting.

(2) Outside the health care setting, the potential for hepatitis B virus (HBV) or human immunodeficiency virus (HIV) infection in the general public following medical waste-related injuries is not likely to be a health concern. However, needle-stick injuries may cause local or systemic secondary infections, similar to injuries from nails.

(3) The increase of in-home health care provides opportunities for the general public to contact medical waste. In addition, other sources of non-regulated medical waste may also present opportunities for medical waste contact.

(4) Based on estimates of the number of medical waste-related HIV and HBV infections and disease cases, occupational health concerns exist for selected

occupations involved with medical waste. Those populations include janitorial and laundry workers, nurses, emergency medical personnel, and refuse workers.

(5) When in effect, the proposed regulations by the Department of Labor's Occupational Safety and Health Administration (OSHA), 'Occupational Exposure to Bloodborne Pathogens; Proposed Rule and Notice of Hearing' (Federal Register 1989;54:23042-139), should decrease workplace medical waste-related injuries and infections nationwide. This decrease should be achieved through increased awareness, regulatory control, and immunization.

(6) Illicit intravenous drug users (IVDUs), who have high rates of HIV (human immunodeficiency virus) and HBV (hepatitus B virus) infection, are a significant source of discarded sharps. (It was thought in 1990 that there were approximately 1.1–1.3 million illegal IVDUs nationwide). The general public could come in contact with these discarded sharps and thus have an increased opportunity for injury and infection. A lack of data prevents estimating the potential HIV and HBV infection rates from IVDU-related waste.

(7) Scientific studies indicate that, outside a living host, numbers of the human immunodeficiency virus (HIV) rapidly decline, and the virus does not remain viable after a few days. (HIV is of course the virus that causes acquired immunodeficiency syndrome, or AIDS.) Thus, persons coming in contact with medical waste outside the health care setting have a very low potential for HIV infection. The hepatitis B virus (HBV), however, does remain viable for an extended time outside a host. Consequently, the potential for HBV infection following contact with medical waste is likely to be higher than that associated with HIV.

(8) The number of persons infected with the human immunodeficiency virus is anticipated to increase in the future. A maximum of <1–4 cases of AIDS per year (<0.003–0.01% of all the 1989 AIDS cases in the United States) were estimated to occur in health care workers as a result of contact with medical waste sharps. However, the increase in the number of persons infected with HIV is expected to increase the potential for medical waste-related HIV transmission in the health care setting.

(9) In 1990, it was estimated that a maximum of approximately 162–321 HBV infections and 81–160 hepatitis B disease cases related to medical waste sharps could occur annually. The 162–321 HBV infections and 81–160 hepatitis B disease cases estimated to occur as a result of contact with medical waste would account, respectively, for 0.05–0.1% of the total number of HBV infections and 0.05–0.1% of hepatitis B clinical disease cases occurring annually in the United States.

(10) Communicable diseases spread within medical facilities are usually the result of community-acquired (pre-existing) or nosocomial (hospital-acquired) infections. Although, theoretically, communicable diseases may be transmitted by medical waste, the probability of such transmission is generally considered to be remote. Appropriate preventive health measures and personal hygiene practices have controlled and should continue to successfully control the incidence of medical waste-related disease transmission within medical facilities.

(11) Medical waste can be effectively treated by chemical, physical, or biological means, such as chemical decontamination, autoclaving, incineration, irradiation, and sanitary sewage treatment. Research indicates medical waste does not contain any

greater quantity or different types of microbiological agents than does residential waste, and viruses present in solid waste tend to adsorb to organic matter and deactivate. Additionally, properly operated sanitary landfills provide microbiological environments hostile to most pathogenic agents. Therefore, untreated medical waste can be disposed of in sanitary landfills, provided procedures to prevent worker contact with this waste during handling and disposal operations are strictly employed. It is worth noting, however, that 158 million tons of municipal solid waste are created yearly nationwide. Medical waste is a part, albeit a small one at 0.3%, of the overall problem of solid waste management. Clearly, the most effective way to deal with this issue is to strive to reduce the amount of waste created, on a small scale in homes or on a large scale in industrial operations. Simultaneously, the impetus to recycle, reuse, and reclaim products is paramount to adequately manage solid waste, including medical waste, now and in the future.

10. Issues of medical waste disposal

10.1. Incineration issues

(1) Should all wastes generated at a hospital (such as the 'municipal', medical, hazardous and radioactive waste fractions) be allowed to be incinerated at an on-site incinerator? Which fractions are allowable if *effective* air pollution control is to be installed and maintained?

(2) Hazardous waste as defined under RCRA is required to be segregated from medical waste before the medical waste is incinerated in hospital waste incinerators, if these incinerators do not have RCRA permits. However, facts show that complete segregation of hazardous waste (e.g., chemicals and cytotoxic agents) from medical waste could be a substantial problem. As a result, it is probable that hazardous waste generated at hospitals will be incinerated along with medical waste without RCRA permits. Is this violating the RCRA regulations?

(3) How can appropriate permit conditions be established?

(4) What are the characteristics and levels of air/solid/water emissions from medical waste incinerators which substantially impact risks?

(5) What is the definition of pathogen destruction efficiency?

(6) Should pathogen emissions be regulated? and how? Shouldn't 'front-end fugitives' also be regulated? by whom?

(7) Should EPA regulate medical waste incineration ash quality?

(8) What are the needed monitoring, sampling and analytical protocols for evaluating the performance of medical waste incinerators?

(9) What is the definition of risk policy for medical waste incinerators?

10.2. Treatment issues

(1) Should EPA develop a regulatory guideline for each medical waste treatment technology which may include autoclaving, chemical disinfection, microwave treatment, etc.?

(2) Does a medical waste treatment technology need a operating permit? and how to establish appropriate permit conditions?

(3) What are the pre-treatment requirements for a medical waste for it to be disposed of in a landfill?

(4) What are the needed monitoring, sampling and analytical protocols for evaluating the performance of medical waste treatment technologies?

(5) What is the definition of risk policy for medical waste treatment technologies?

11. Conclusion

At first view, it would appear that this highly regulated industry (i.e., hospitals) has little regulation regarding the disposal of its waste. The beach wash-ups in 1987 and 1988 have resulted in great concern and scrutiny by the public. In addition, the concern over AIDS and other communicable diseases coupled with right-to-know legislation has resulted in concern by all elements of hospital personnel; hospitals need to be re-evaluated relative to their waste collection and disposal practices. Based on the current technology assessment, environmentally-safe incineration of medical waste is achievable, if:

- State-of-art incinerators are installed;
- Modern air pollution control equipment is used; and
- Incinerator operators are properly trained.

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