United States
Environmental Protection
Agency

Office of Research and
Development
Washington, DC 20460

EPA/625/4-91/030
December 1991

Technology Transfer

EPA

Seminar Publication

Medical and Institutional Waste Incineration:

Regulations, Management, Technology, Emissions, and Operations

EPA/625/4-91/030
December 1991

Seminar Publication

Medical and Institutional Waste Incineration:

Regulations, Management, Technology, Emissions, and Operations

Center for Environmental Research Information
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

Printed on Recycled Paper

Disclaimer

This document has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Preface

Many medical waste incinerators in the United States are not designed to adequately handle the complex waste streams generated by modern medical facilities. Issues of concern to both the public and medical facility owners/operators are: What are the adverse health and environmental effects from improper handling and disposal of generated wastes? What can I do with waste generated at my facility? Do regulations exist to protect the public?

The U. S. Environmental Protection Agency (EPA) was aware of some of these concerns, and research was underway when Congress passed the *Medical Waste Tracking Act* in the Summer of 1988. The purpose of that legislation was to respond to public concern and to gather information in limited geographic areas. Meanwhile, the public, regulators, and facility owners/operators continued to ask: Is medical waste being handled and disposed of properly? Is technology available to answer these concerns? What must be considered when responding to these questions? Can correct answers to these questions be found? To respond to some of these concerns, EPA's Center for Environmental Research Information decided to sponsor a series of seminars to provide information on technologies that could be applied to medical waste handling and disposal.

A series of five seminars was held, beginning in October, 1989, in Providence, Rhode Island, and concluding in February, 1990, in Tallahassee, Florida. This document is a summary of the material presented at these seminars.

Because the document was written based on notes from the presentations, it presents information as it was known in 1989. Thus the *Medical Waste Tracking Act*, for example, is discussed in the present verb tense, even though the demonstration program has been completed. Additionally, some other information is no longer applicable, and may even be obsolete, in light of regulations being developed at the federal level as a result of the 1990 Clean Air Act Amendments. Furthermore, existing state regulations may provide more specific guidance than that presented in this document. The document, however, contains general principles that remain of interest to those who are concerned with medical waste handling and disposal.

Contents

Figures

Tables

Acknowledgments

The material presented in this seminar series was prepared by Jacqueline Sales, HAZMED, and Lawrence G. Doucet, P.E., Doucet & Mainka, P.C., to match their presentations. Ms. Sales presented the bulk of the material contained in Chapter 2, while Mr. Doucet and John Bleckman, Doucet & Mainka, presented the remaining material. Karen Natsios Rehmus, Eastern Research Group, Inc., was responsible for logistical arrangements for the seminars and was on site at all locations to provide support.

Anne C. Jones, Eastern Research Group, Inc., prepared the written manuscript from handout material available from the seminars. Denis J. Lussier and Justice A. Manning, U.S. EPA, Center for Environmental Research Information (CERI), prepared most of the narrative slides.

James A. Eddinger, EPA, Office of Air Quality Planning and Standards, and Kristina L. Meson, EPA, Office of Solid Waste, are especially acknowledged for their peer review of this document. Justice Manning, CERI, was the project officer for both the seminars and this publication.

Chapter 1
Introduction

Medical waste management is becoming an increasingly important issue as medical institutions face public fears and perceptions, tightening legislation, and fewer disposal options. Many medical institutions are responding to these problems by reevaluating their waste management practices, particularly the treatment and disposal methods they are now using. Because landfill space is vanishing and because more states are requiring onsite treatment and disposal of medical wastes, onsite incineration of medical waste is becoming an increasingly attractive waste management option.

To address this growing interest in medical waste incineration, the U.S. Environmental Protection Agency (EPA) initiated a series of seminars entitled *Medical and Institutional Waste Incineration: Regulations, Management Technology, Emissions, and Operations* presented from October 1989 to February 1990 in 5 of the 10 EPA Regions. These seminars were designed to assist those responsible for managing medical waste in understanding the applicable regulations; developing waste management plans; selecting appropriate waste management options, including incineration; determining data collection needs; and managing the selection, procurement, and operation of medical waste incinerators.

The information presented in the seminar series, including information on combustion theory, air pollution control equipment, and operator training needs, is summarized in this document. Generally, it is organized to follow the sequence of the major topics presented in the seminar series. Because only that information presented at these seminars is summarized here, this document is not a source of the most recent information on these subjects. More recent information on these subjects is available.[1,2,3]

1.1 Organization of the Report

This report is organized into four chapters, in addition to this introduction and references. The existing federal, state, and local regulations governing medical waste management, treatment, and disposal are discussed in Chapter 2, which focuses on the *Medical Waste Tracking Act of 1988* as an example of how medical waste may be regulated in the future. Pending regulations and guidelines that affect the management of medical waste also are presented.

The administrative and technical issues that must be considered when options for medical waste treatment are investigated, including methods for waste minimization, are summarized in Chapter 3. Principal technologies used to treat and dispose of medical waste, including steam autoclaving, shredding with chemical disinfection, and incineration, also are summarized.

The basics of combustion theory, the major incineration technologies in use, emission control strategies, pollution control equipment, and other equipment used in incineration systems are summarized in Chapter 4. Also covered in this chapter are the types of data critical to incinerator design, the operating parameters that can affect incinerator efficiency and emissions, and some of the basic regulatory and permitting requirements for incinerators.

Additional considerations specific to developing a waste management plan for medical waste incinerators are discussed in Chapter 5. A method for ensuring that an institution's needs will be met throughout the incinerator selection, procurement, and acceptance phases is presented, and common pitfalls that can occur during selection and procurement are identified. The chapter is concluded with an outline of the information that should be covered by operator training programs to ensure the safe and proper operation of medical waste incinerators.

1.2 Sources of Information

Most of the report is drawn from the materials handed out at the seminars, which were organized as a document entitled *Seminar—Medical and Institutional Waste Incineration: Regulations, Management, Technology, Emissions, and Operations*.[4] These materials are reprints of slides used at the seminars as well as three papers written by Lawrence G. Doucet.[5,6,7] Chapter 2 summarizes the presentation made by Jacqueline Sales at the seminar series. Most of Chapter 3 is based on Reference 5. Portions of Chapter 4 and most of Chapter 5 are a summary of Reference 6. Other major sources of information concerning combustion theory, some descriptions of incinerator equipment, and operator training needs were drawn from Reference 8. The portion of Chapter 4 covering air pollution control devices was summarized primarily from Reference 9.

Chapter 2
Overview of Medical Waste Regulations and Guidelines*

A broad spectrum of federal, state, and local regulations and guidelines govern the management of medical wastes. The federal regulations and guidelines that affect the handling of medical waste are discussed in this chapter. Guidelines developed by EPA and other entities are discussed, and a selection of state and local regulations that might affect medical waste management and disposal planning are summarized. Regulatory issues affecting medical waste incinerators are discussed in Chapter 4.

2.1 Historical Perspective

For a number of years, various federal agencies and organizations, including the National Institutes of Health (NIH), the Centers for Disease Control (CDC), and the Nuclear Regulatory Commission (NRC), have regulated or issued guidelines for handling and treating medical wastes. Many states and some local governments also regulate the management of these wastes. In May 1986, EPA actively became involved in overseeing medical waste management by issuing its *Guide for Infectious Waste Management*,[10] in which a number of practices, including those for waste segregation, storage, packaging, treatment, transport, and disposal, are recommended.

Despite guidelines and regulations, a number of incidents involving the mismanagement of medical waste have occurred. In the summer of 1988, improper handling and storage of medical waste became a heated public issue when beaches along the east coast were closed after medical and other wastes washed up along shore. Reports of syringes, needles, and other medical waste found around dumpsters, gutters, and other public areas added to the furor over improperly disposed of medical waste. Furthermore, fear of AIDS and other communicable diseases has been increasing steadily. Although no evidence has been found linking mismanagement of medical waste to any case of injury or infection in the general public, Congress enacted *The Medical Waste Tracking Act*[11] in the fall of 1988 in response to these public concerns.

As a result of this increase in public and Congressional concern and the growing volumes of medical waste generated, increasingly stringent regulations are likely to be promulgated. To prepare for new requirements, those involved in the management or treatment of medical waste should familiarize themselves with all levels of regulations and guidelines in effect, proposed, or under consideration. The *Medical Waste Tracking Act* with resulting regulations and other existing and proposed federal regulations and guidelines that affect how medical waste is managed are discussed in the sections below. Selected state and local regulations and guidelines are reviewed briefly, as well.

2.2 Medical Waste Tracking Act of 1988

2.2.1 Overview of the Act

The *Medical Waste Tracking Act* (MWTA),[11] a 2-year program running from June 1989 to June 1991, most likely will have a significant impact on how medical waste is handled and disposed of in future years. The Act defines medical waste as "...any solid waste which is generated in the diagnosis, treatment, or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biologicals...." In enacting the law, Congress recognized that medical waste requires special handling and disposal and that experience gained from a pilot program would serve as a guide to its proper management. Moreover, Congress anticipated that a regionwide demonstration program would provide a realistic test for determining the need for a national program to track medical wastes.[12]

The MWTA amended the *Resource Conservation and Recovery Act* (RCRA) by adding Subtitle J, which establishes the demonstration tracking program for medical wastes as a first step in minimizing irresponsible medical waste disposal. Subtitle J is designed to ensure that medical waste is properly packaged and separated from general refuse to protect workers, the public, and the environment from possible risk. The program also will set up a tracking system to identify and increase the accountability of those who generate, transport, and dispose of these wastes. Since much of this waste no longer will be handled as ordinary refuse, EPA expects that less medical waste will wash up on beaches and float on waterways in the participating states.[12]

Initially the Act specified New York, New Jersey, Connecticut, and the seven states bordering the Great Lakes as participants in the demonstration program.[13] These states were allowed to decline to join the program, and other states were invited to petition into the program; New York, New Jersey, Connecticut, Rhode Island, and Puerto Rico are those which have elected to participate.

*As noted in the preface, the seminar series was begun in late 1989. The regulatory situation as it existed at that time is presented in this chapter.

EPA, in cooperation with the participating states, will review and evaluate the demonstration program. As required by the law, the Agency will report to Congress on program accomplishments, limitations, and any problems encountered during the 2 years.[1,2] This information is being used to design guidelines for the nonparticipating states and to develop proper environmental laws for future national application.[14]

2.2.2 Description of the Demonstration Program

A description of the program is provided because it was part of the seminar.[4] EPA expects that many components have been and will be incorporated into state regulatory programs, and many also may become part of future EPA regulations.

2.2.2.1 Facilities and Wastes Covered by the MWTA

The EPA rule covers only medical waste generated in the participating states by institutional and commercial sources such as hospitals, medical clinics, drug treatment centers, clinical and research laboratories, nursing homes, funeral homes, veterinary practices, and military vessels at port. The rule defines the following medical wastes as regulated medical waste (RMW):[15]

- Cultures and stocks of infectious agents
- Human pathological wastes
- Human blood and blood products
- Sharp implements—used and unused
- Contaminated animal waste
- Isolation waste from patients with highly communicable diseases

Waste excluded from coverage includes:

- Domestic sewage
- Hazardous waste
- Household waste
- Treated and destroyed waste
- Human remains to be cremated or interred
- Samples collected for enforcement purposes

2.2.2.2 Segregation, Packaging, and Handling of Medical Waste

Before medical waste leaves the site where it is produced, generators must take certain precautions to protect workers, handlers, and the public from exposure to the material.[15] First, generators must separate it from general trash. Then, to ensure that the waste is packed securely and will not leak, medical waste must be packaged in rigid, leak-resistant containers. Sharps, such as scalpels and needles with their residual fluids, must be separated from other medical waste and packed into puncture-resistant containers, and uncontained fluids must be poured into tightly stoppered, break-resistant containers.

The regulation is designed to prevent packages from being damaged during shipping and handling, thus preventing accidental contact with workers or the public. Therefore a rigid outer container, or secondary packaging, generally is required during shipping. Specific standards also apply to regulated wastes that are stored during preparation for shipping and disposal.

When secondary packages, such as bins, buckets, and boxes, are reused, they must be cleaned thoroughly. Primary packages—inner containers—are not reusable and are handled as medical wastes. Generators must label and mark packages clearly, identifying the contents, the generator, and the transporter.

If the generator treats or destroys waste onsite, records of quantity must be maintained. If offsite waste is accepted by the facility for destruction, the source of the waste, date received, quantity of waste, and date destroyed must be recorded and maintained. Those facilities with onsite incinerators further must maintain incinerator operation logs and must submit two reports to EPA summarizing information collected during the first and third 6-month periods of the demonstration program.

2.2.2.3 Tracking Medical Waste

As medical waste moves through the disposal process, it must be carefully tracked.[15] When a generator finishes preparing a package of medical waste bound for treatment or disposal at another site, the generator fills out a tracking form, a copy of which must be retained for recordkeeping. Only those transporters who have registered with EPA may carry this waste from the generator to its final destination. In the case of a generator of small quantities (less than 50 lbs) of medical waste, a log shows who is carrying the waste and where the waste is going, and a tracking form is initiated by the transporter. Transporters must comply with all handling requirements as outlined for generators and also must maintain records and file reports with EPA.

As the waste travels to its final disposal site, the tracking form goes with it. Each transporter and owner or operator of a treatment or disposal facility signs and keeps one copy of the tracking form. The generator receives the final copy, indicating the waste was received at an authorized disposal facility. When a generator fails to receive a copy of the completed tracking form, an exception report must be filed with the state.

The operations at the disposal facility may be controlled by other federal, state, and local laws and regulations. All facilities disposing of regulated medical waste, however, must manage the waste in accordance with the handling requirements outlined above, comply with all tracking form requirements, maintain all required records, and prepare and submit to EPA reports (such as discrepancy reports) that detail any discrepancies between a shipment and its accompanying papers. These standards apply to all disposal facilities receiving RMW even if the facility is located in a nonparticipating state.

2.2.2.4 Enforcement

EPA has the authority to issue formal and informal enforcement actions if a facility is in violation of the regulations.[15] Examples of serious violations include transporting RMW without a tracking form, improper marking and labeling, failure of the transporter to notify EPA of its intent to transport RMW, and failure to file exception or discrepancy reports. Criminal actions also may be filed, when appropriate.

2.3 Other Regulations and Guidelines Affecting the Management of Medical Waste

Although the information gathered through the MWTA demonstration program might be used to develop federal regulations, a number of regulations that affect the management of medical waste are in place or will be promulgated shortly. State and local regulations tend to vary widely in their stringency, leading to a need for medical waste managers to understand many levels of regulations before designing their medical waste management programs. Because of the trend towards more stringent regulation, existing guidelines could become law, so these, too, should be reviewed before medical waste management procedures are developed or modified and before disposal facilities are designed or updated.

2.3.1 Federal Regulations and Guidelines

Most medical waste is considered a nonhazardous solid waste (i.e., ordinary trash) under Subtitle D of RCRA and thus is not subject to any special handling or disposal requirements unless more stringent state or local regulations exist. Certain types of medical waste, however, are covered by Subtitle C of RCRA (as hazardous waste)[16] or by Nuclear Regulatory Commission regulations.[17] Additionally, some medical waste handling procedures will be regulated by the Occupational Safety and Health Administration (OSHA) under the proposed Blood-borne Pathogen Rule.[18]

2.3.1.1 RCRA Subtitle C

RCRA Subtitle C regulates solid waste that is either listed in the regulation as hazardous or that exhibits certain hazardous characteristics: ignitability, corrosivity, reactivity, or toxicity characteristic leachate procedure (TCLP) toxicity (the leachate contains levels of certain metals that exceed specified concentrations).[16] The only wastes listed in Subtitle C that may be generated by medical facilities, which would include laboratory wastes and chemotherapy treatment wastes, are certain chemotherapy agents. Other wastes generated by medical facilities may, however, exhibit hazardous characteristics. If the waste could exhibit hazardous waste characteristics, it generally must be tested. If testing demonstrates that the waste exhibits hazardous characteristics, the generator then must comply with Subtitle C requirements. These requirements specify waste packaging, storage, labeling, transport, and disposal procedures. Subtitle C also requires a hazardous waste manifest to accompany the waste from generation to final disposal.

Generators of less than 100 kilograms (220 pounds) of hazardous waste per month are excluded from the hazardous waste regulations if they dispose of the waste at a state-licensed or permitted Subtitle D facility, such as a municipal solid waste landfill, and if they meet all state requirements, which may be more stringent than federal requirements. Generators of 100 to 1,000 kilograms per month of hazardous waste must comply with all RCRA regulations but are exempt from certain reporting requirements. Generators of 1,000 kilograms or more per month of hazardous waste must notify EPA and obtain a federal ID number; prepare a manifest for offsite shipments of hazardous waste; treat, store, and dispose of hazardous waste in a federally permitted facility; and meet reporting and recordkeeping requirements.

2.3.1.2 NRC Regulations

Current NRC regulations address the disposal of low-level radioactive waste.[17] These regulations specify that animal carcasses and liquid scintillation fluids containing less than 0.50 microcuries/gram of tritium or carbon-14 are "biomedically exempt" and may be discarded without special procedures under NRC regulations. Those containing more than 0.50 microcuries/gram of these substances or containing other radiological components must be disposed of in accordance with NRC regulations under 10 CFR Part 20.

Because some radiological components, or radionuclides, of medical waste can decay in storage, the NRC allows waste containing radiologicals with a half-life of 65 days or less (except iridium) to be stored until a minimum of 10 half-lives have passed. For example, a waste with a half-life of 6 days must be held for at least 60 days, at which point it can be disposed of as a nonradioactive waste if residual radioactivity is measured at equal to or less than background levels. If the waste is disposed of as a nonradioactive waste, all radiation warning labels must be removed or obliterated before disposal.

Recordkeeping requirements also are specified for medical wastes held in storage for disposal as nonradioactive waste. Information such as storage dates, background levels, radioactivity detection instruments used, nuclides disposed, date of disposal, and a contact person must be maintained for 3 years.

2.3.1.3 Proposed OSHA Regulation for Health Care Facilities

In May 1988, OSHA proposed a health standard regulation covering the management of medical wastes to ensure the protection of any workers who may be exposed to human blood or body fluids in the course of their employment.[18] The facilities to be covered include all health service facilities, funeral services, and crematories.

The proposed regulation is intended to protect health care workers from occupational exposure to blood-borne diseases. Personal protection during activities such as drawing blood, housekeeping requirements, sanitation and waste disposal procedures is addressed, and specifications for accident prevention are provided. A general duty clause is in effect and is applied routinely even though the regulations are not final yet. The general duty clause requires employers to vaccinate at-risk employees for hepatitis B, identify and label contaminated linen, sterilize and disinfect reusable equipment, and require employees to follow CDC's handwashing guidance[19] and wear appropriate personal protective equipment.

2.3.1.4 EPA Guidelines

EPA recommends that each facility prepare an Infectious Waste Management Plan addressing procedures such as segregation, storage, transport, treatment, disposal, contingency planning, and training.[10] Also provided in the EPA guidelines are recommendations for procedures to follow, including labeling of infectious waste, packaging types to use, limiting access to storage areas, and transporting wastes in leak-proof trucks or dumpsters. Preferred treatment methods also are indicated. These preferred treatment methods include incineration or steam autoclaving for most types of waste and discharge of treated liquids and ground-up solids to the sewer system; land disposal of treated solids and incinerator ash is the recommended disposal method.

2.3.1.5 CDC Guidelines

CDC epidemiologically defines outbreaks of disease in the health care environment and in the community and develops strategies for prevention and control. It is not a regulatory agency and therefore provides only recommendations for managing one portion of medical waste—infectious waste. CDC defines infectious waste as isolation wastes, microbiological cultures and stocks, blood and blood products, pathological wastes, and sharps.[19] CDC specifies secure packaging and recommends incineration or decontamination of wastes, although blood and body fluids may be discharged to the sewer system. More recently, CDC issued *Recommendations for Prevention of Human Immunodeficiency Virus (HIV) Transmission in Health Care Settings*, or "Universal Precautions."[20] These recommendations state that all patients should be considered potentially infected with HIV or other bloodborne diseases, unless specifically diagnosed otherwise.

2.3.2 NIH Standard Operating Procedures

The NIH (as well as similar organizations and facilities) has developed standard operating procedures for the management and disposal of infectious waste.[21] Infectious waste is defined as waste contaminated with infectious agents and includes items such as surgery and autopsy wastes, patient care wastes, and other contaminated wastes. NIH specifies secure packaging, special labeling, onsite incineration or steam autoclaving, and disposal of treated waste and ash as general waste.

2.3.3 Joint Commission on Accreditation of Healthcare Organizations (JCAHO) Standards

The overall framework in which medical facilities must operate is outlined by the Joint Commission on Accreditation of Healthcare Organizations (JCAHO).[22] In general, JCAHO requires compliance with all applicable laws and regulations. It also mandates that policies and procedures for identifying and managing hazardous/infectious waste be instituted. JCAHO also establishes standards for safety, patient care, staffing, and training programs at health care organizations. Standard IC.2, Infection Control, and Standard PL1.6, Hazardous Waste Management, are specified in the JCAHO Accreditation Manual for Hospitals (AMH).[22] These standards address labeling of containers, space and equipment requirements, waste stream segregation, and training for all employees who use or are exposed to hazardous and infectious materials, emergency response teams, and supervisory personnel. The training must address regulatory requirements and must cover internal disaster plans, emergency response plans, and contingency plans. JCAHO also requires that a system must be instituted to safely manage hazardous materials and wastes from points of entry to final disposal. Additionally, committees must be established to annually review the waste management plan and evaluate its effectiveness.

2.3.4 State and Local Regulations

State and local regulations vary widely. The way in which waste from medical facilities is defined by a state or locality can profoundly affect the volume of waste that must be handled as potentially infectious. State and local regulations also can determine the available options for treatment and disposal. About half the states and several major cities mandate that certain types of medical waste (i.e., that defined as potentially infectious by the regulatory authority) be treated on site, restrict its offsite transport, and/or prohibit it from being landfilled.[7] Many additional states are planning similar requirements in the next few years. These restrictions, combined with requirements or recommendations for incinerating infectious waste, heavily encourage the use of onsite incineration as an infectious waste treatment method. Approximately 30 states designate or define infectious waste for regulatory or policy-making purposes, and at least 7 states include infectious wastes under their hazardous waste regulations. Approximately 20 states[7] are planning to either promulgate new infectious waste legislation or tighten existing infectious waste legislation or guidelines very shortly.**

To see how infectious waste is regulated at the state level, it is useful to summarize the existing or planned requirements of the 10 states originally selected for the MWTA program.[13] Of these states, 6 (New York, New Jersey, Illinois, Minnesota, Pennsylvania, and Wisconsin) had medical waste regulations in place at the time the MWTA was promulgated and 4 (Connecticut, Indiana, Ohio, and Michigan) had no medical waste regulations. All 10 states, however, were either amending or developing medical waste regulations. Most of the states were requiring or will require special packaging and labeling (New York, New Jersey, Minnesota, Pennsylvania, Connecticut, and Ohio) and nearly all were requiring or will require treatment of at least some types of waste prior to disposal (only Michigan

**This information dates from 1988. A total of 45 states now have some form of medical waste regulations, 14 states track waste using a chain-of-custody system, and 42 states require treatment before disposal (Meson, Kristina, U.S. EPA, Washington, DC, personal communication, November, 1991).

has no plans for requiring treatment). Recordkeeping requirements were less universal, with only four states (New York, New Jersey, Illinois, and Connecticut) requiring or proposing to require recordkeeping by generators, transporters, and treatment/disposal facilities. Half of the states (New York, New Jersey, Illinois, Connecticut, and Ohio) did or will require some type of tracking program. Permits for disposal facilities were or will be required in all the MWTA states. Transport permits were or will be required in New York, New Jersey, Illinois, Connecticut, and Ohio. None of the MWTA states, however, had existing requirements for permitting generators; Ohio was planning to require generator permitting.

Chapter 3
Technical Overview of Medical Waste Management and Treatment

Medical waste is a heterogenous mixture of many types of wastes that can include general waste ("trash"), potentially infectious waste, and pathological waste. Many facilities that generate medical waste also generate hazardous waste, radioactive waste, and other types of special waste. The technical options available for treating and disposing of medical wastes vary depending on the types and quantities of waste generated by the facility. Thus, the first step in choosing waste management options is to identify, or characterize, and quantify wastes. Waste characterization and quantification data then can be used to select the waste management technology options most suited to the institution's needs. The technical and administrative aspects of characterizing wastes, minimizing waste generation rates, and selecting treatment and disposal options are discussed in Section 3.1. The technical options for treating and disposing of the types of waste generated at medical institutions are described in Section 3.2. Further discussion of the administrative aspects of designing a waste management plan is presented in Chapter 5.

3.1 Technical and Administrative Considerations

3.1.1 Definitions and Sources of Medical Waste

One of the first steps in managing medical waste is to determine the types and quantities of waste generated and whether it should be classified as solid waste, potentially infectious waste, hazardous waste, or radioactive waste. The regulatory definitions for hazardous or radioactive wastes are clear; however, definitions of medical waste that should be managed and disposed of as potentially infectious vary depending on which regulation or guideline is considered. Each type of waste and its sources are discussed in the sections below.

3.1.1.1 Potentially Infectious Waste

A portion of the medical waste stream from most health care and similar institutions is categorized or is regulated as being potentially infectious. Other common terms for infectious waste are biohazardous waste, biological waste, biomedical waste, contaminated waste, pathogenic waste, pathological waste, red-bag waste, and regulated medical waste (RMW). Regardless of regulatory definition, however, a waste is infectious when *all* of the following conditions are met simultaneously:[4]

- The presence of a virulent pathogen
- Sufficient concentration of that pathogen
- Presence of a host
- Portal of entry
- Host susceptibility

Because infectious waste often is defined in broader terms, medical facilities must take into account the regulatory definitions of infectious waste, interpret these definitions to their particular situation, create internal policies and protocols for its proper and safe management, and administer a proper waste management program.

Definitions and designations for infectious waste vary widely from state to state and in different federal regulations and guidelines. Some of the various federal designations of infectious waste include those by the CDC,[19] the EPA *Guide for Infectious Waste Management*,[10] the *Medical Waste Tracking Act of 1988*,[11] and others. CDC defines infectious waste as any waste from microbiology laboratories, pathological waste, sharps, and blood or blood-product waste.[19] More recently, CDC recommended "universal precautions," which suggest that all patients be considered potentially infected with AIDS or other blood-borne diseases until otherwise diagnosed.[20] EPA's *Guide* designations are more specific: isolation waste, cultures and stocks of infectious agents, human blood and blood products, pathological waste, contaminated sharps, and contaminated animal carcasses, body parts, and bedding all are considered infectious.[10] "Optional infectious waste," which is waste that may not pose a risk, also is listed in the *Guide*. EPA leaves the decision of whether optional waste should be handled as infectious to a responsible authorized person or committee at the individual facility. Among these optional wastes are surgery and autopsy wastes, miscellaneous laboratory wastes, dialysis unit wastes, and contaminated equipment. The *Medical Waste Tracking Act* defines regulated medical waste (RMW) to include cultures and stocks of infectious agents, human pathological wastes, human blood and blood products, sharps, contaminated animal wastes, and isolation wastes.[4]

The definitions presented above encompass increasingly broad infectious waste designations. The volume of medical waste generated by institutions that would be defined as infectious by older CDC designations[19] is about 3 to 5 percent of the total volume.[5] The EPA *Guide*[10] would categorize 7 to 15 percent of medical waste as infectious,[5] and CDC's universal precautions definition of infectious waste[20] would label 60 to 80 percent of all medical waste as infectious.[5] Depending on the hauler or the disposal facility used for medical waste, the contractor might consider anywhere from none to all of the waste from a medical facility infectious for the purposes of setting hauling or disposal fees and handling procedures.[5] Because infectious wastes are defined in so many ways, because the general public tends to perceive all medical waste as potentially infectious, because offsite disposal contractors may define any medical waste as potentially infectious, and because of the recent CDC recommendations concerning "universal precautions," many institutions may begin categorizing all patient-contact wastes as potentially infectious and may choose to define infectious wastes in very broad terms.[5]

3.1.1.2 Chemical/Hazardous Waste

Hazardous wastes are defined in RCRA Subtitle C,[16] and either are listed or meet certain characteristics of ignitability, corrosivity, reactivity, or TCLP toxicity (see Section 2.3.1.1). Many chemotherapy wastes may be defined by RCRA as hazardous, and therefore are regulated by 40 CFR Parts 260-265. If a container has less than 3 percent by weight of the original amount or capacity of hazardous material remaining, it is considered empty and does not require disposal as a hazardous waste (40 CFR 261.7). This exemption *does not* apply to seven chemotherapy drugs listed by EPA as acutely toxic (40 CFR 261.33f).

Sources of potentially hazardous chemical wastes include clinical and research laboratories, patient-care activities, pharmacies (spills and expired items), physicians' offices (outdated items), physical plant departments, or buildings and grounds departments (e.g., pesticides and solvents).

3.1.1.3 Sources of Radioactive Waste

Low-level radioactive waste may be produced through a number of activities, including those associated with research laboratories, clinical laboratory procedures, and nuclear medicine procedures such as diagnostic and therapeutic applications. These wastes may take several forms. Low-level radioactive solid waste may include animal carcasses, clinical items, and other contaminated "dry" materials. Liquid radioactive wastes include liquid scintillation fluids (LSC), biological and chemical research chemicals, and wastes stemming from the decontamination of radioactive spills.

3.1.2 Waste Disposal Evaluations

After the sources and general types of waste have been identified, detailed waste disposal evaluations should be performed. These evaluations encompass a data collection phase in which the type and volume of waste is characterized fully and quantified. Improper characterization or quantification can lead to the improper selection of treatment methods, and in the case of incineration, may result in an underutilized incinerator or in severe management or operational problems.[5] As part of the evaluation, existing waste management practices should be reviewed to determine areas for change or improvement.

In performing a waste characterization, the task can be made easier by designing forms on which classes of waste, e.g., dry and solid (such as paper, plastic, cloth, or laboratory animal cage waste), pathological (such as carcasses and tissue, body parts, or cadavers), or liquid (such as solvents and chemicals or blood and body fluids), can be noted by type of waste. After all waste types have been determined, the waste can be characterized based on its composition and constituents, forms and categories (e.g., highly compacted or high ash content), physical parameters (e.g., solid or liquid), and chemical parameters (e.g., organics, inorganics).

Waste volumes can be quantified in several ways. One way would be to use waste generation factors. As an example, in 1968, the Incinerator Institute of America (IIA) published factors that show approximate waste generation rates at various institutions and other facilities (see Table 3-1).[23] A more accurate means of estimating waste generation rates is to use offsite hauling and disposal records, such as billing records, and analyses of waste volumes and frequencies of disposal. Calculations using this type of information, however, could lead to gross inaccuracies if waste managers do not account for variabilities in waste container fullness or in the compaction densities of container contents. Records of truck-scale weighings, if available, may be useful. The most accurate method, however, is to perform a waste survey and weighing program over a period of perhaps 2 weeks.

Waste surveys can be performed in a number of different ways.[5] The survey can use waste collected from a disposal area or from specific sources. Waste can be weighed or its weight can be estimated. The waste can be quantified by bulk volumes such as carts or by individual containers, such as bags. Waste can be selected randomly or all waste can be weighed or estimated. Waste types can be identified specifically or approximations can be used (see Section 4.1.3.1 for a description of waste-type approximations). The extent of the survey can encompass from one day to several weeks.

3.1.3 Waste Minimization

Following a waste characterization, the feasibility of minimizing waste generation should be evaluated. Three basic approaches to minimizing potentially infectious, hazardous, or radiological waste can be taken: ***source reduction***, in which potential wastes are reused, recycled, or recovered; ***substitution***, in which items destined to become a part of the hazardous waste stream are replaced with nonhazardous substitutes (or eliminated from use); and ***segregation***, in which all three types of special-handling wastes (potentially infectious, hazardous, or radiological wastes) are separated from the general waste stream at the institution.

Segregation is one of the most practical and cost-effective waste management policies an institution can implement.[5] If potentially infectious waste can be segregated from general waste, substantial costs savings for waste treatment can be realized.

Some waste minimization schemes also become a useful tool when waste is treated or disposed. For example, emissions of acid gases such as hydrogen chloride (HCl) from incinerators can be minimized if polyvinyl chloride (PVC) plastics can be substituted by nonchlorinated plastics. In this case, HCl

Table 3-1. Incinerator Institute of America Waste Generation Factors

Classification	Building Types	Quantities of Waste Produced
Industrial buildings	Factories	Survey must be made
	Warehouses	2 lbs per 100 sq ft per day
Commercial buildings	Office buildings	1 lb per 100 sq ft per day
	Department Stores	4 lbs per 100 sq ft per day
	Shopping centers	Study of plans or survey required
	Supermarkets	9 lbs per 100 sq ft per day
	Restaurants	2 lbs per meal per day
	Drug stores	5 lbs per 100 sq ft per day
	Banks	Study of plans or survey required
Residential	Private homes	5 lbs basic & 1 lb per bedroom
	Apartment buildings	4 lbs per sleeping room per day
Schools	Grade schools	10 lbs per room & 1/2 lb per pupil per day
	High schools	8 lbs per room & 1/2 lb per pupil per day
	Universities	Survey required
Institutions	Hospitals	15 lbs per bed per day
	Nurses or interns homes	3 lbs per person per day
	Homes for aged	3 lbs per person per day
	Rest homes	3 lbs per person per day
Hotels, etc.	Hotels — 1st class	3 lbs per room and 2 lbs per meal per day
	Hotels — medium class	1-1/2 lbs per room & 1 lb per meal per day
	Motels	2 lbs per room per day
	Trailer camps	6 to 10 lbs per trailer per day
Miscellaneous	Veterinary hospitals	Study of plans or survey required
	Industrial plants	
	Municipalities	

Source: Reference 23.

emissions might be controlled by substitution alone, obviating the need for expensive emission control equipment. Other types of wastes such as solvents can be segregated as part of an overall waste segregation program. Containers of solvents, when fed directly into incinerators, can cause severe operating problems. These same solvents when segregated from other waste and injected into an incinerator designed to burn solvents as auxiliary fuel can be disposed of safely, as well as more economically.

3.1.4 Disposal Option Selection

The next step in the administration of the waste management process is to evaluate waste disposal options. First, technical and economic evaluations should be undertaken. These evaluations include investigating the sites and utilities that might be available for the treatment or disposal of waste, calculating the costs of all viable options for comparison purposes, and reviewing regulatory and permitting requirements for each viable option to determine additional costs or difficulties that might be associated with the choices selected. Next, the planner can develop a matrix of alternatives that incorporates the technical evaluations, schematics, and economic analyses, leading to a group of appropriate options. Along with the disposal options that could be considered, variables such as degree of onsite or offsite treatment might be listed. For example, all waste can be treated and disposed of offsite. Alternatively, selected types of wastes can be treated onsite, while other types (such as hazardous waste) might be treated and disposed of offsite. Finally, all wastes might be treated onsite. Options also will include alternative technologies, combinations of treatment technology choices, and add-on equipment. Requirements for redundancy and backup systems should be included, and any siting considerations should be noted.

When estimating costs, the planner should note not only capital costs and annual operating and maintenance costs, but also should determine the annualized costs (for example, the capital recovery costs) of owning and operating the equipment.

In selecting a waste management option, the planner should consider the total economic picture, the contingencies and outages that may arise, future scenarios and potential changes, such as to regulations and standards, and noneconomic issues such as siting feasibility and public opposition to one or more treatment or disposal options.

3.2 Treatment and Disposal Options for Potentially Infectious Waste

3.2.1 Biomedical Waste Options

Medical waste-generating facilities have a number of waste management options from which to choose, depending on the quantity and nature of the waste they generate, state and local regulations or recommendations, and economic factors. These options can be divided into onsite and offsite treatment and disposal methods. Onsite treatment methods include various types of disinfection and shredding techniques as well as incineration. Incineration is the primary offsite treatment method, but several offsite disposal firms have recently installed steam autoclaves with shredders. Incinerator ash must be disposed of by landfilling. Treated waste may be disposed of by landfilling, incineration, or discharge of ground-up solids to the sewer system. Treated liquids also can be discharged to the sewer system if approved by the local sewer authority. Various alternative treatment technologies and options are discussed, along with the advantages and disadvantages of each choice, in the following sections.

3.2.1.1 Onsite Treatment Technologies

Few treatment and disposal technologies are available for managing the increasing volumes of medical waste generated annually at many facilities. The principal technologies for treating potentially infectious waste are steam autoclaving, shredding with chemical disinfection, and incineration. The advantages and disadvantages of each technology are summarized in Table 3-2. Innovative and emerging technologies, such as glass-slagging systems, high-temperature plasma systems, and systems combining shredding and radiation are not yet commercially available.[5] The principal technologies of autoclaving, shredding with chemical disinfection, and incineration are the focus of this section; however, a few emerging technologies are discussed briefly. The various types of incinerators and their operation are covered more fully in Chapter 4.

Steam Autoclaving

In autoclaving, steam is used to kill pathogenic microorganisms in the waste. Autoclave types and designs generally differ in their levels of steam contact efficiency and in the volume of waste that can be processed within the shortest possible time. The contact efficiency of any autoclave system is a direct function of steam penetration into the packages of waste being treated by the system. Factors such as waste type and density, packaging materials, and waste loading procedures directly affect the extent of steam penetration and the exposure times necessary for effective treatment. If sterilization is not achieved within a reasonable time, inadequate steam penetration may be the cause.

Three basic types of autoclave systems are available: gravity systems, prevacuum systems, and retort systems. Steam pressure alone is used in gravity systems to evacuate air from the autoclave chamber (see Figure 3-1). Prevacuum systems use pumps to evacuate air from the autoclave chamber, and retort systems are designed to operate at high steam pressures. Gravity systems require more time to process waste than prevacuum systems, which typically require more time than retort systems. Gravity systems typically operate with steam at 15 psi and corresponding steam temperatures of 250°F. About 15 minutes of *direct* steam contact typically are required under these conditions, but cycle times are usually 60 to 90 minutes per load to allow for steam to penetrate fully into densely packed wastes. More rapid and efficient steam penetration can be achieved by prevacuum systems and by retort systems, which use high-pressure steam to minimize cycle times.

A variation on these three basic systems is an autoclave system that functions as a combined, integral prevacuum autoclave and general waste compactor. After the autoclave cycle is completed, treated biomedical waste is ejected automatically into an integral trash compactor. The treated biomedical waste

Table 3-2. Comparisons of Onsite Biomedical Waste Treatment Technologies*

Principal Treatment Technologies	Advantages	Disadvantages
Autoclaving	Low costs Low space requirements Ease of implementation Simplicity of operation	Limited capacity Not suitable for all wastes Waste handling system/bags Odor control Waste volume unchanged Waste appearance and form unaltered
Shredding/chemical disinfection	Substantial volume reduction Suitable for many wastes Relative simplicity Alters waste forms	Relatively high costs Manual waste handling Limited capacity Liquid effluent contaminants Room noise and chemical disinfectant levels Only one manufacturer Level of treatment achieved
Incineration	Disposes of most waste types and forms Suitable for large volumes Large weight and volume reductions Sterilization and detoxification Heat recovery	Relatively high costs High maintenance and repair requirements Stack emissions and concerns Permitting difficulties Public opposition

Source: Reference 5.

*There have been many recent developments in alternative treatment technologies since the seminar series was presented. The final Report to Congress on Medical Waste Management in the United States, which should be published in 1992, will have a discussion of new and emerging treatment technologies and their efficacy (Meson, Kristina, U.S. EPA, Washington, DC, personal communication, November, 1991.)

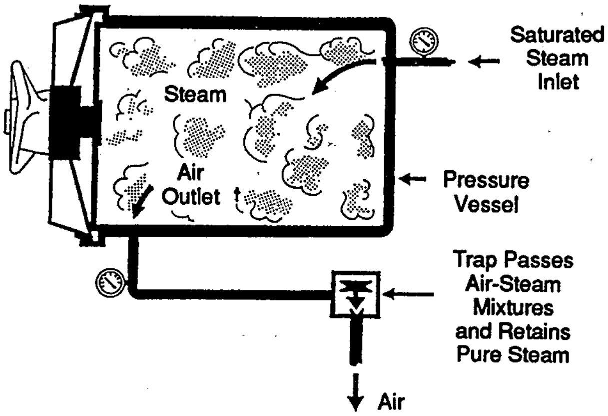


Figure 3-1. Gravity steam-autoclaving system.
Source: Reference 24.

and general trash then are compacted into a close-coupled, roll-off container for offsite disposal.

To ensure that autoclave systems are loaded, operated, and maintained correctly, temperature monitoring and frequent sterilization-efficiency testing must be performed; these procedures are mandated in some states. The sterilization-efficiency testing, known as biological challenging, involves introducing heat-resistant spores into worst-case waste loads and measuring the extent of spore inactivation or destruction.

The principal advantages of steam-autoclave systems are low capital and operating costs, relatively small space requirements, and ease of operation. The principal disadvantages include the relatively limited processing capacity of these systems, their need for special waste packaging and handling to ensure steam penetration, and the need for odor control and drainage management. Autoclaving is not recommended for carcasses and body parts, wastes with high liquid content, and volatile chemical waste such as chemotherapy waste. Also, autoclaving does not change the appearance of the waste; biohazard symbols on packaging, blood stains, needles, and syringes remain identifiable.

Shredding with Chemical Disinfection

A system that uses chemical disinfectants in combination with shredding has been developed recently.* A midwestern firm developed a treatment system that shreds and treats waste with sodium hypochlorite. Systems are available both for small operations, such as laboratories, and for large operations, such as hospitals. In the large-capacity system, which can handle up to about 1,500 pounds per hour, waste is loaded onto a conveyor belt that lifts it into a high-torque, low-speed shredder (see Figure 3-2). At the bottom of the shredder, the waste is discharged into a hammermill, where it is granulated. During both the shredding and granulating stages, the waste is sprayed with a sodium hypochlorite solution. A perforated conveyor belt separates the solids from the slurry. The liquids then are discharged to the sewer, and the solids are retained for offsite disposal. Airborne contamination is contained by drawing air from the system and passing it through a series of prefilters and a chlorine-resistant HEPA filter before being discharged to the atmosphere.

*Several systems are now available. (Doucet, Lawrence G., Doucet & Mainka, P.C., personal communication, November, 1991).

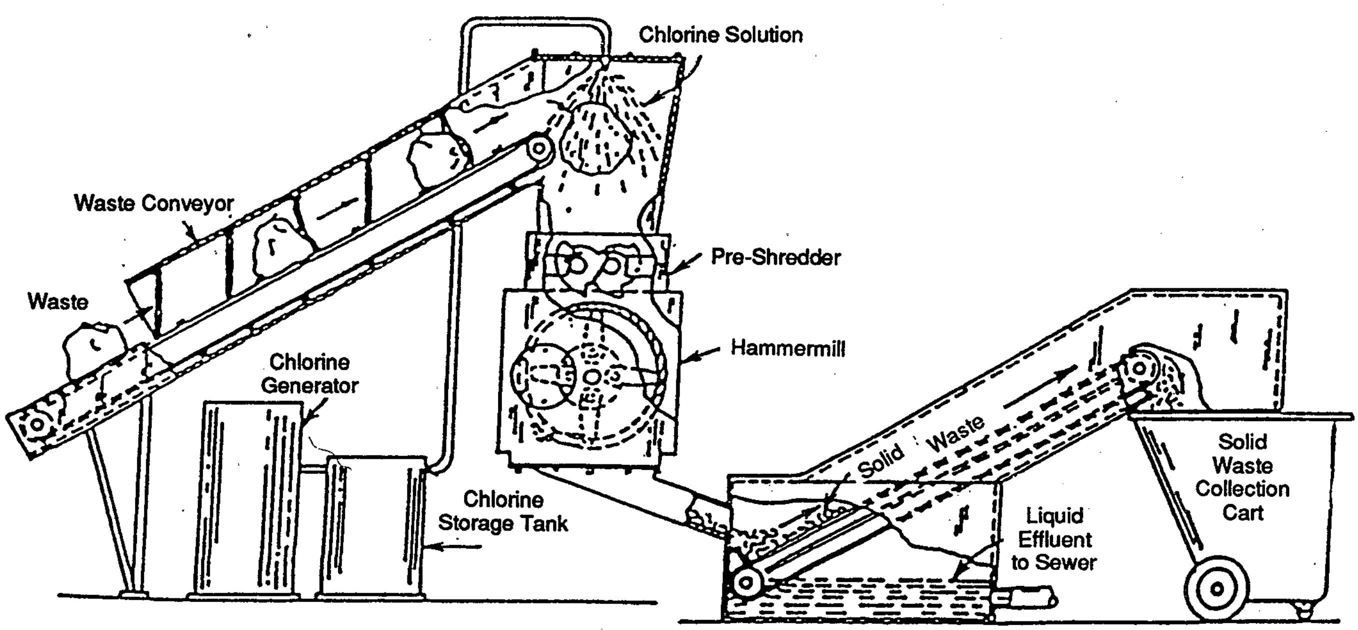


Figure 3-2. System for shredding with chemical disinfection.
Source: Reference 25.

The principal advantages of this system are its relative simplicity and its ability to substantially reduce waste volume (reportedly as high as eight to one). All waste items are rendered unrecognizable, making it suitable for treating all types of wastes except pathological remains and large metal objects, which could damage the hammermill.

The principal disadvantages are the relatively high costs of the system (as much as a medium-capacity incinerator); limited throughput capacities; potential problems or concerns with slurry contaminants, workplace disinfectant concentrations; noise levels; and bioaerosol emissions. Furthermore, chemical disinfection systems do not provide sterilization, which may be a problem in the states in which sterilization is required. Discharge permits might be required for the slurry, and adherence to occupational workplace standards might require special precautions.

Incineration

Incineration is a process using controlled, high-temperature combustion to destroy organics in waste materials. Modern incinerators are designed to maximize combustion efficiencies (see Figure 3-3).

Three standard, or widely used, basic incineration technologies are suitable for combusting medical waste:

- Multiple-chamber incinerators, which are constructed with several chambers (two or three), generally operating under excess air conditions.
- Rotary-kiln incinerators, which feature cylindrical, refractory-lined combustion chambers that rotate the waste from the loading end to the discharge end, where it is discharged as ash.
- Controlled-air incinerators, which first burn wastes under starved-air conditions in a primary chamber, then burn the resulting combustion products and volatile gases under excess-air conditions in a secondary chamber.

These incinerators and the advantages and disadvantages specific to each system for incinerating medical waste will be discussed in detail in Chapter 4. In addition to these incinerator types, various innovative incineration designs have been introduced over the years, many of which have been either technologies transplanted from hazardous waste incinerator applications or untried experimental concepts.

The onsite incineration of medical waste has many advantages. Incineration sterilizes pathogenic wastes; provides volume and mass reductions of up to 90 to 95 percent; converts offensive waste, such as animal carcasses, to innocuous ash; can provide waste-heat recovery; and in some cases, can be used simultaneously to dispose of hazardous chemicals and low-level radioactive waste. Current and developing medical waste legislation encourages the use of onsite incineration. As discussed in Chapter 2, many states restrict offsite management of infectious waste, and some require or recommend incineration as the preferred method for treating potentially infectious waste. Furthermore, onsite incineration solves the problems of locating suitable offsite treatment and disposal facilities, which have become increasingly scarce and expensive in recent years.

The disadvantages of onsite incineration are increasingly stringent regulatory restrictions and permitting difficulties,** public opposition to incineration, and residue disposal restrictions that in some cases require incinerator ash to be handled

**EPA's Demonstration Program has shown a decrease in the number of onsite incinerators because of difficulties meeting state air-quality requirements. (Meson, Kristina, U.S. EPA, Washington, DC, personal communication, November, 1991.)

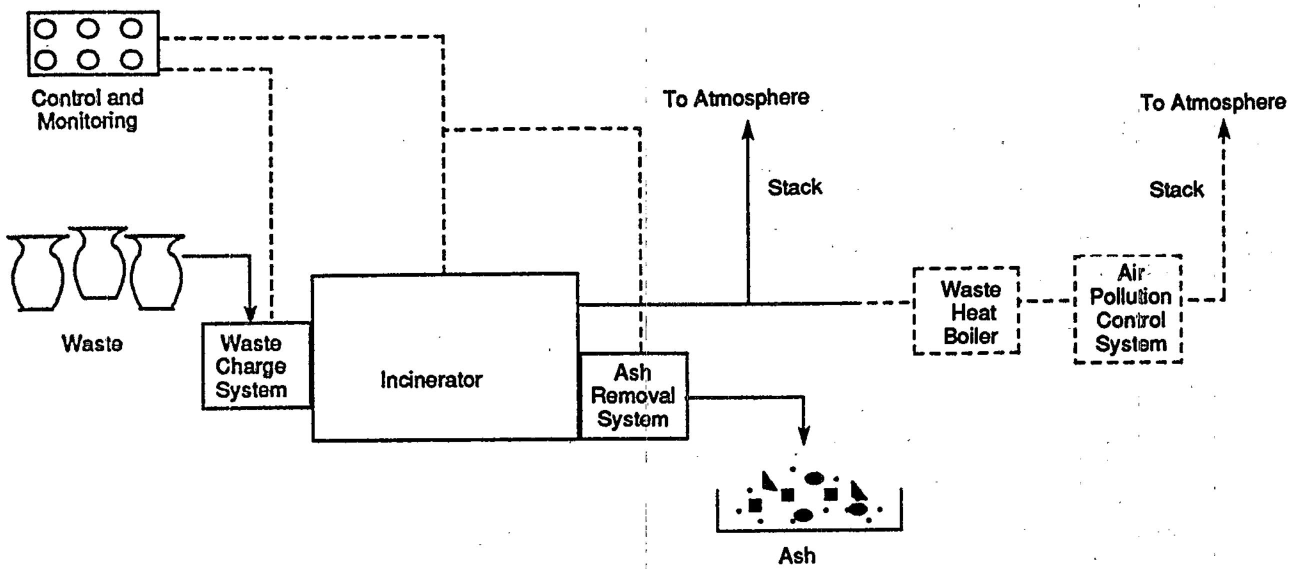


Figure 3-3. Major components of an incineration system.
Source: Reference 8.

as special or hazardous waste. All of these disadvantages increase the costs of onsite incineration and in many cases can make the onsite incineration of medical waste prohibitively expensive. Because onsite incineration is the overwhelming choice for many facilities, medical waste managers need to understand the basics of incinerator types, system components, operations, regulatory requirements, and selection and procurement considerations. These issues are discussed in detail in Chapters 4 and 5.

Emerging Technologies

Two emerging technologies with potential application to medical wastes include irradiation and microwave treatment.[†] In irradiation, ionizing radiation from a source such as Cobalt 60 or an electron beam is used to destroy pathogens. The technique is similar to that currently being used to sterilize medical supplies, food, and other consumer products. Following treatment, the wastes are typically ground, compacted, and shipped to a landfill. In microwave treatment, wastes are ground and shredded to improve system effectiveness and sprayed with water. An auger moves the waste past a series of microwave power packs that subject the waste to microwaves. The microwaves destroy pathogens and heat the waste to 200°F. Volatiles and water are driven off during the process.[26]

3.2.1.2 Offsite Treatment and Disposal

Offsite treatment and disposal may be chosen when onsite treatment is not available. Some of the advantages and disadvantages of offsite treatment and disposal are summarized in Table 3-3.

Three options available as alternatives to onsite treatment are:

- Contract disposal—The facility pays a fee to an independent, commercial firm to transport and dispose of infectious waste at an offsite facility, typically an incinerator. The waste may be hauled and incinerated at the contractor's incinerator, or the contractor may haul the waste to another contractor's incinerator or to an onsite incinerator at a hospital. Rates for these services are usually set on a cost-per-pound or cost-per-box basis, and packaging materials may be provided as part of the service. Occasionally, contractors offer refrigerated trucks for longer-term storage and transport.
- Disposal at another institution's incinerator—Some hospitals with excess incineration capacity offer disposal services to other institutions, either on a fee-for-service or shared-cost basis.
- Disposal at a regional incineration facility—An independent hospital group or association might own and operate a regional facility, either at a member hospital site or some other location. The facility may be developed, administered, and financed by the association itself or by a private developer.

The advantages of contracted offsite treatment and disposal include simplicity and short implementation time relative to designing, building, and starting up an onsite system. Additionally, for the generator, siting and permitting problems are avoided, capital investment needs are eliminated, and building space and support services are not required. Regional or shared-service facilities have additional advantages over onsite treatment facilities—economies of scale can be realized, a single permit covers the treatment of waste from all facilities in the region, and centralized operation allows the resources of several institutions to be pooled.

The major disadvantage of offsite treatment and disposal is that reliable, reputable, and affordable contractors and facilities may be difficult to find in certain areas of the country. Most existing offsite incinerators are operating at peak capacity, and adding capacity is not simple and may be infeasible. Several states have moratoriums on new incinerators or make the siting or permitting of new facilities very difficult. Additionally, most hospitals are reluctant to incinerate waste from other hospitals, and regional incineration facilities are limited in some geographic areas because of siting and permitting problems.

A further disadvantage of contracted offsite transport and disposal is the high annual cost. Onsite incineration systems often realize payback periods of less than 2 years when compared

[†]In its final report to Congress on Medical Waste Management in the United States, EPA will present an evaluation of a number of new and emerging treatment technologies and their efficacy (Meson, Kristina, U.S. EPA, Washington, DC, personal communication, November, 1991).

Table 3-3. Comparisons of Offsite Biomedical Waste Treatment and Disposal Methods

Principal Options	Advantages	Disadvantages
Offsite disposal –Commercial facility –Another institution's incinerator –Regional facility	Minimal capital investment Minimal onsite space requirements Simplicity Short implementation time Onsite disposal permitting avoided	Locating reliable and reputable firms and facilities Potential liabilities and concerns High annual costs Special packaging requirements Manifesting and tracking
Regional or shared-service incineration facility*	Favorable economics Single permit Centralized operations	Siting and permitting difficulties Special packaging and transport requirements Manifesting and tracking "Hazardous" designation (some states)

*vs. individual onsite incinerators

Source: Reference 6.

with offsite disposal costs. As an example, typical annualized onsite incineration capital and operating costs average about $0.05 to $0.20 per pound, whereas contracted offsite disposal may cost from $0.30 to $2.00 per pound. The *Medical Waste Tracking Act*[11] and similar state legislation also add to the costs of offsite disposal with the packaging, manifesting, and transporting requirements of the regulations developed under these laws.

3.2.2 Chemical/Hazardous Waste Options

Several chemical waste management and disposal options are available to hazardous waste generators, including minimization, recycling/recovery, chemical treatment, physical treatment, thermal treatment, and disposal. These options are subject to the hazardous waste management regulations specified in 40 CFR Parts 260-265. Procedures to minimize hazardous waste generation include modifying the processes that produce the waste by eliminating the use of the substance or by using a nonhazardous substitute. Volume reductions might be achievable, and reclaiming or recycling may be possible—the waste may be recovered directly, distilled and recovered, or reclaimed through waste exchange.

3.2.3 Radioactive Waste Options

Four basic methods of treatment and disposal are available to low-level radioactive waste generators. The waste may be concentrated and confined to allow the material to decay in storage (see Section 2.3.1.2). Alternatively, it may be diluted and dispersed by discharging to the sewer system, or volume reduction and dispersion can be achieved by incineration. The final option may be to transport the waste to an offsite low-level radioactive waste disposal facility. The management and disposal of low-level radioactive waste are subject to the NRC regulations under 10 CFR 20.[17]

Chapter 4
Incineration of Medical Waste

Onsite incineration is becoming a preferred method of medical waste treatment for most institutions. Numerous difficulties can arise, however, when incineration systems are not designed for the types or volumes of wastes generated at each site. To help waste management personnel at hospitals and other institutions in the selection, procurement, and operation of onsite incineration systems, the basic principles of combustion and variations in operating parameters that may affect incinerator performance are reviewed in this chapter. The various types of incinerators are described, the general system layout in typical incinerator types is indicated, and the advantages and disadvantages of each type are discussed. The chapter continues with a discussion of incinerator air emissions and types of air pollution control devices that can be used to control emissions. Finally, a summary of incinerator permitting and other regulatory issues is given.

This chapter is not intended to be a complete guide to the incineration of medical waste. For more detailed information on this subject, the reader is referred to EPA's 1990 handbook entitled *Operation and Maintenance of Hospital Medical Waste Incinerators*.[8] Additional, more technical, information is available from references cited in this handbook, as well as from consultants and vendors.

4.1 Technical Aspects of Medical Waste Incineration

4.1.1 Principles of Combustion

Incineration is a combustion process in which waste is reduced to ashes through a chemical reaction.[8] This reaction involves rapid oxidation of the organic substances in the waste and auxiliary fuels, releasing energy and converting the organic materials to an oxidized form. Four basic principles are involved in the combustion process: the basic chemical reactions, the combustion air requirements, the thermochemical relations, and the volumetric air flow.

4.1.1.1 Chemical Reactions

During combustion, the carbon and hydrogen components of the waste react with gaseous oxygen to produce carbon dioxide, water, and heat. Other, more complex reactions occur as well, but the general basis for *complete* combustion can be represented by this principle. Incomplete combustion results in the production of carbon monoxide (CO) and compounds known as products of incomplete combustion (PICs). PICs are unburned hydrocarbons and reformed molecules, some of which may be considered health threats if released to the atmosphere at sufficiently high concentrations or rates. The presence of sulfur, nitrogen, chlorine, and metals in the waste also contribute to air emissions problems during the combustion process. The reactions of these waste constituents and resulting emissions will be discussed in Section 4.2.1.

4.1.1.2 Combustion Air

The theoretical amount of oxygen required for complete combustion is known as the stoichiometric or theoretical oxygen. Specific stoichiometric oxygen requirements are determined by the nature and quantity of the combustible material to be burned. Combustion oxygen usually is obtained from atmospheric air. The additional oxygen (or air) available for combustion over and above the stoichiometric amount is called "excess air." When the amount of oxygen (or air) is less than the stoichiometric amount, it is called starved air or substoichiometric air. Under starved-air conditions, incomplete combustion occurs, which results in the production of CO and PICs. The formation of these combustion products is characterized by the release of smoky emissions containing unburned hydrocarbons and volatiles.

Maximum combustion temperatures are achieved at stoichiometric conditions. If excess air is present, combustion temperatures drop because energy is used to heat the combustion air from ambient temperature to the combustion chamber temperature. During starved-air combustion, combustion temperature also drops because complete combustion cannot occur. A graph of temperature as a function of excess air percentages is presented in Figure 4-1.

As excess air increases, several components of incinerator emissions change. Oxygen levels increase, and carbon dioxide concentrations decrease (although the total carbon dioxide generated does not change, the dilution of carbon dioxide with excess air produces a lower concentration). Thus oxygen and carbon dioxide concentrations of incinerator emissions are useful indicators of excess air levels and are used to monitor the combustion process. Too much excess air results in lower temperatures, consumption of more auxiliary fuel, more entrainment of particulates, larger flue-gas volumes, greater system horsepower needs, and less efficiency. Too little excess air results in poor combustion and increased emissions.

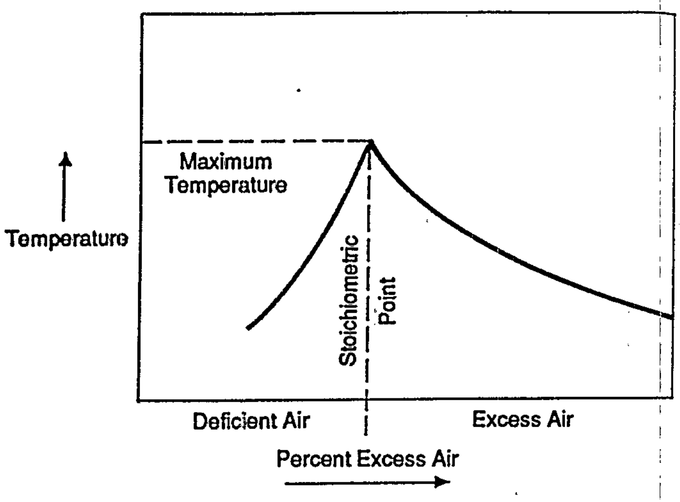


Figure 4-1. Control of temperature as a function of excess air.
Source: Reference 27.

4.1.1.3 Thermochemical Relations

Thermochemical calculations are used to estimate heat release and heat transfer associated with combustion. These calculations permit the amount of energy released by the combustion process and its transfer to the environment to be determined. The amount of heat released during the combustion process can be calculated from the heating value of the waste and supplemental or auxiliary fuels. This heat is released to the environment through incineration effluents and other pathways, such as radiative heat losses.

4.1.1.4 Volumetric Gas Flows

Gas flows through a combustion system are a major consideration in the design and operation of the system. The total gas flow comprises combustion air, gaseous products of combustion, and evaporated moisture in the waste. A primary goal of the design and operation of a medical waste incineration system is the complete destruction of pathogens and the complete combustion of organic materials. Achieving this goal requires the waste to be exposed to high temperatures for a sufficient retention time. Flue-gas retention time is a function of incinerator chamber volume and volumetric gas flow rate, which in turn is dependent on the flue-gas temperature. Proper incineration requires sufficient combustion air, as well as sufficient combustion temperatures, sufficient time during which combustion reactants are exposed to the high combustion temperature, and sufficient mixing (turbulence), which ensures good contact of the waste/fuel with the combustion air. These latter factors typically are termed the three Ts of combustion: time, temperature, and turbulence.[4]

4.1.2 Types of Incinerators

Three major incinerator types have been used to incinerate medical waste: multiple-chamber incinerators, rotary-kiln incinerators, and controlled-air incinerators. These three types of incinerators are discussed below. A few innovative incinerators have been used, but these systems vary widely in success and a description of these systems is beyond the scope of this document.

4.1.2.1 Multiple-Chamber Incinerators

Multiple-chamber incinerators were developed during the 1950s and until the mid-1960s were the type used almost exclusively by hospitals and similar institutions. To control combustion and limit emissions, these systems use settling chambers and are designed to operate at very high excess-air levels. Air emissions are unacceptably high with these systems, thus air pollution control equipment must be installed. Additionally, many states require performance and operating conditions that these systems cannot meet without substantial upgrading and state-of-the-art combustion control equipment.[6]

Few multiple-chamber incinerators are being built, but many older systems remain. Unfortunately, many of these are operated improperly, leading to emission problems. Furthermore, some were built with grates in their primary combustion chamber. These grates allow uncombusted waste to fall into the ash pit, exposing cleanout operators to unburned infectious waste and sharps.

Multiple-chamber incinerators are of two basic types: the inline design and the retort design (see Figures 4-2 and 4-3). Combustion gases flow straight through inline incinerators, turning vertically only. In the retort design, gases turn horizontally as well as vertically. Retort multiple-chamber incinerators are more compact, and they are more efficient than inline incinerators at small capacities.

4.1.2.2 Rotary-Kiln Incinerators

Rotary-kiln incinerators feature cylindrical, refractory-lined combustion chambers that rotate on a slightly inclined, horizontal axis (see Figure 4-4). Waste is loaded at one end, and the rotation of the incinerator moves the waste to the other

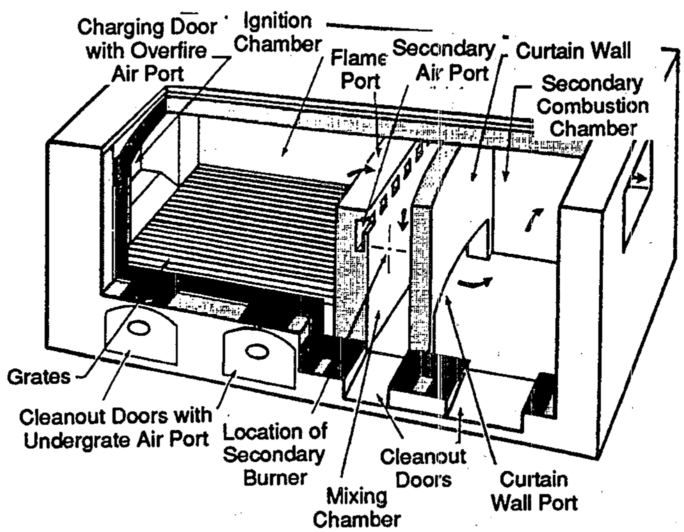


Figure 4-2. Inline multiple-chamber incinerator with grate.
Source: Reference 8.

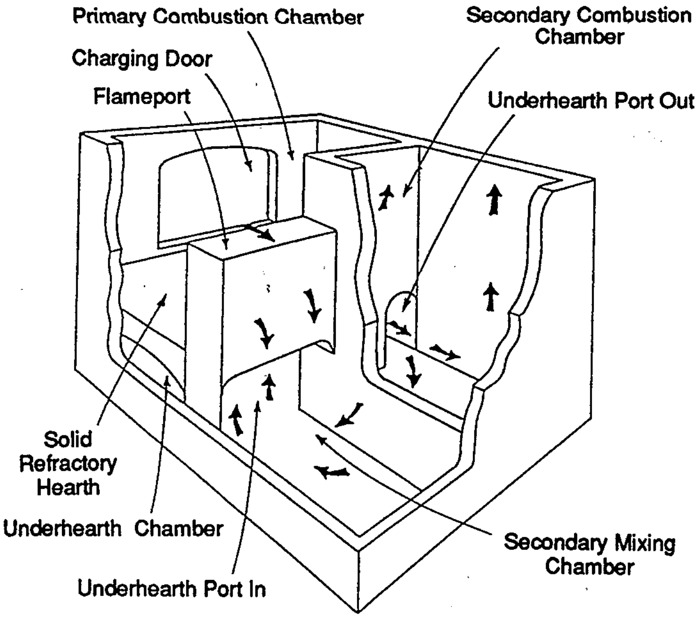


Figure 4-3. Retort-type multiple-chamber incinerator.
Source: Reference 4.

end, where it is discharged as ash. To comply with air emissions standards, rotary-kiln incinerators require air pollution control equipment and secondary combustion chambers.

Rotary-kiln incinerators have been used widely for incinerating hazardous waste and have been promoted recently for use with medical waste. The rotation promotes excellent turbulence, produces a good-quality ash, and allows for continuous-feed operations (i.e., the incinerator does not have to be shut down to clean out ashes). To date, however, very few rotary-kiln incinerators are in operation for medical waste treatment. Their high capital and operating costs, which exceed those for other incinerator technologies, hamper their more widespread use. Repair and maintenance costs are particularly high because the waste tumbles through the rotary chamber, abrading the refractory lining. Another disadvantage is that small-capacity rotary-kiln incinerators may require additional waste processing before incineration. In such applications, waste may need to be shredded before it enters the rotary chamber. As the waste is shredded, usually with a mechanism termed an auger feeder, waste spills from infectious-waste bags onto the feed mechanism, leading to potential maintenance and clean-up hazards.

4.1.2.3 Controlled-Air Incinerators

Controlled-air incinerators use two or more separate combustion chambers to burn waste (see Figure 4-5). The first chamber operates under starved-air conditions to volatilize the moisture in the waste, vaporize the volatile fraction of the waste, and combust the fixed carbon in the waste. The combustion gases are then passed into the secondary (or combustion chamber) of the system where combustion air is regulated to provide excess-air conditions and complete the combustion of the volatiles and other hydrocarbons emitted from the primary chamber. Good turbulence is provided to promote mixing of the combustion gases and combustion air. The gas/air mixture then is burned at high temperatures. Both primary and secondary chambers usually are controlled automatically to maintain optimum burning conditions with varying waste-loading rates, composition, and characteristics.

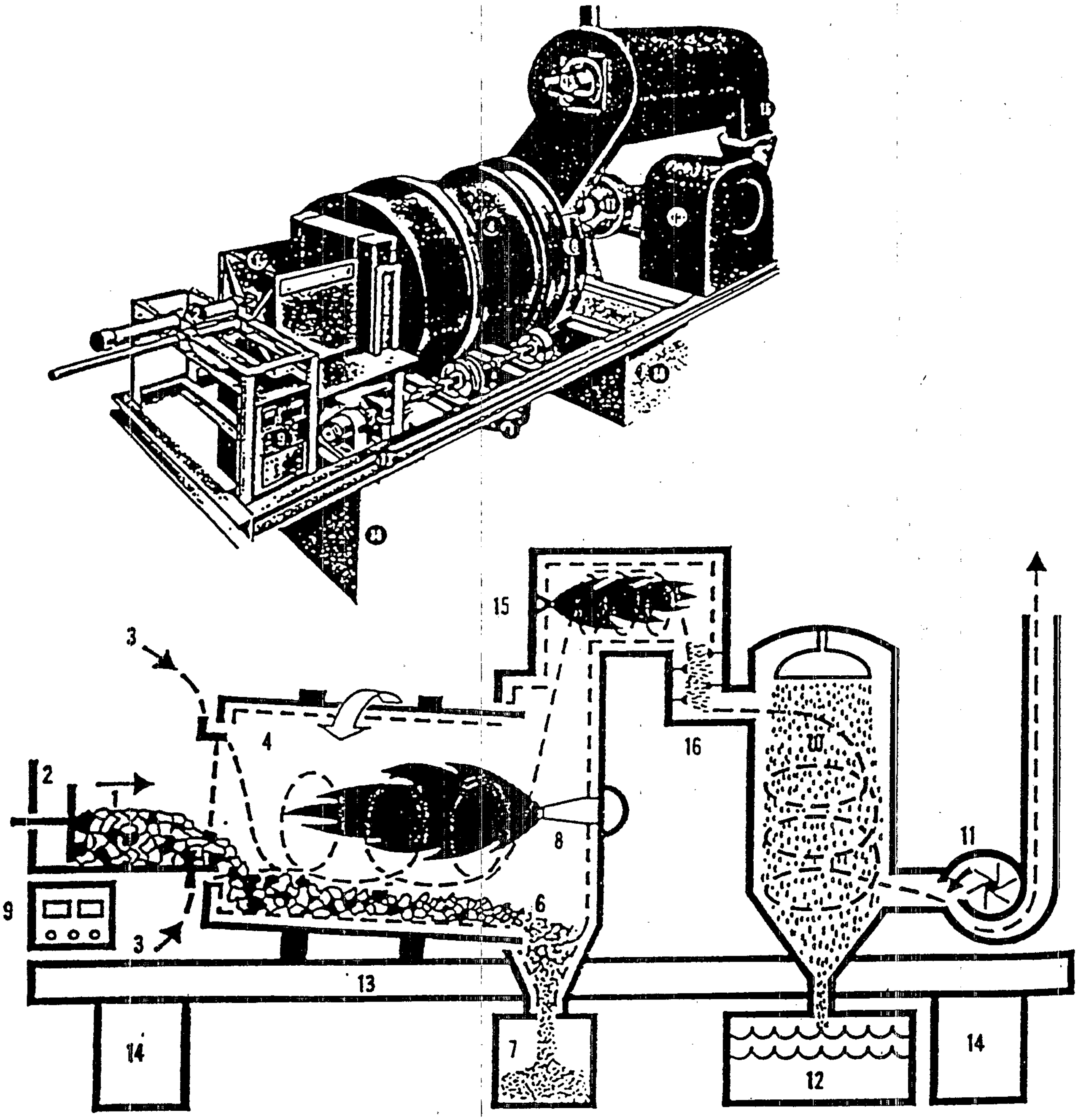
Controlled-air incinerators have several advantages over the older, multiple-chamber incineration technology. The starved-air condition of the primary chamber allows slow, quiet combustion to occur, which minimizes entrainment of particulates in the combustion gases and thus reduces particulate emissions to the atmosphere. The lower temperatures achieved in this chamber help avoid the melting and fusion temperatures of most metals, glass, and other noncombustibles, thus minimizing slagging and clinker formation. The high temperatures and excess-air conditions of the second chamber help ensure complete combustion of volatile gases, reducing hydrocarbon emissions. Because of their low cost and relatively clean combustion, controlled-air incinerators are extremely popular—more than 95 percent of all medical waste incinerators installed in the last 20 years are controlled-air incinerators.[6] Their popularity is deserved because of their low cost and their relatively clean combustion. Until the last 3 to 5 years, most controlled-air systems did not require pollution control equipment to meet air quality standards, but as states pass increasingly stringent regulations, these systems possibly may need additional emission controls.

4.1.3 Incinerator Operating Modes

Medical waste incinerators can be operated in three modes: batch, intermittent-duty, and continuous-duty. Batch incinerators burn a single batch load of waste, typically only once per day. Waste is loaded manually, burned under automatically controlled conditions, and automatically cooled; the ashes then are removed manually. Intermittent-duty incinerators, loaded continuously and frequently with small waste batches, operate less than 24 hours per day. A typical intermittent-duty operating cycle for a system with manual ash removal includes a 15- to 30-minute period for cleanout of ash from the previous day, a 15- to 60-minute period for preheat of the incinerator, a 12- to 14-hour waste-loading period, a 2- to 4-hour burndown period, and a 5- to 8-hour cool-down period. Continuous-duty incinerators are operated 24 hours per day and use automatic charging systems to charge waste into the unit in small, frequent batches. All continuous-duty incinerators operate using a mechanism for automatically removing the ash from the incinerator.

4.1.4 Incinerator Design Parameters

All incinerators, regardless of type, must be designed with a number of considerations in mind. The type and volume of waste per unit time (or waste generation rate) are primary considerations for determining required incineration capacity and the design and sizing of the incinerator and its components. The first steps in selecting and designing an incinerator include characterizing the waste to be incinerated and determining the amount of waste generated per unit time. These factors then can be used to determine the size and rating of the primary and secondary chambers and the total capacity of the system.



1 Waste Incinerator
2 Auto-cycle feeding system:
feed hopper, pneumatic feeder, slide gates
3 Combustion air in
4 Refractory-lined, rotating cylinder
5 Tumble-burning action
6 Incombustible ash
7 Ash bin
8 Auto-control Burner Package:
programmed pilot burner
9 Self-compensating instrumentation controls
10 Wet-Scrubber Package:
stainless steel, corrosion-free wet scrubber;
gas quench
11 Exhaust fan and stack
12 Recycle water, flyash sludge collector
13 Support frame
14 Support frame
15 Afterburner chamber
16 Precooler

Figure 4-4. Rotary-kiln incinerator.
Source: Reference 28.

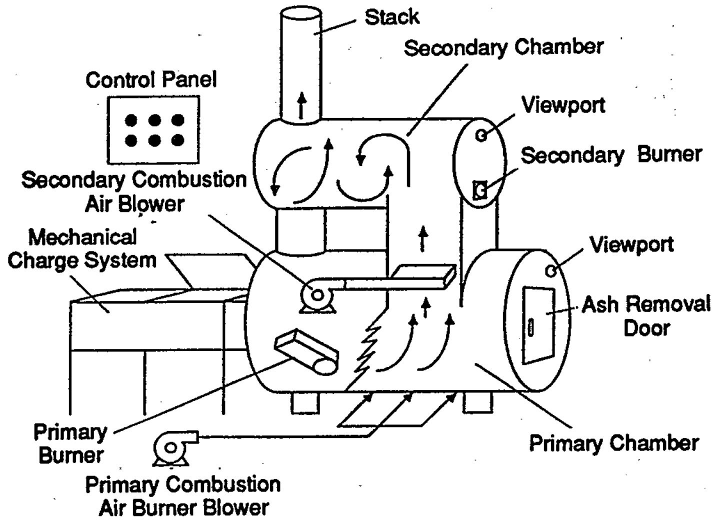


Figure 4-5. Major components of a controlled-air incinerator.
Source: Reference 29.

4.1.4.1 Waste Characterization

Incinerators must be properly designed for the specific properties and characteristics of the waste to be processed. Incinerator designs typically are specific to facility needs or applications and to waste types and characteristics, such as ash content, moisture, and heating value. The general terminology sometimes used when making purchase-order specifications, such as "trash," "infectious waste," or "biological waste," does not define waste types or specific characteristics adequately. Using this terminology could lead to the installation of an unsuitable incinerator. To mitigate problems that can arise when waste is not characterized adequately, the Incinerator Institute of America (IIA) developed a classification system to categorize wastes into seven types.[23] The definitions of Types 0 through 4 are presented in Table 4-1. Types 5 and 6 are not associated with medical waste. These characterizations commonly are used to classify waste types approximately, and the popularity of this classification is enhanced through its use by most incinerator manufacturers, who rate their equipment in terms of IIA waste types.

Alternatively, and more appropriately, waste streams can be sampled to determine their approximate composition, or component breakdown, and then published data such as that presented in Table 4-2 can be used to characterize the waste. Laboratory analysis of the sampled waste to determine "exact" heating values, moisture content, etc., is not recommended because of high cost and lack of significant benefit over other acceptable approximations.[6]

A key factor in specifying an incineration system for a particular application is the clear identification of the ranges of waste properties and waste characteristics. Use of averages could lead to inadequate incinerator capacity and could jeopardize performance.

4.1.4.2 Incinerator Sizing and Rating

Primary Combustion Chamber

Primary combustion chambers generally are rated in terms of burning capacity, that is, the pounds of a specific waste that can be burned per hour. Incinerators usually have different ratings depending on the type of waste burned. Different types of waste have different heating values. Primary combustion chambers are sized and designed according to two criteria: heat-release rate and burning rate. The heat-release rate is calculated by multiplying the burning capacity in pounds/hour by the heating value of the waste in Btu/pound and dividing by the volume of the chamber in cubic feet, that is:

$$HR = \frac{\text{capacity x heating value}}{\text{primary chamber volume}} = \text{Btu/hr/cu ft}$$

where:

HR = heat release rate

or

$$HR = \frac{\text{(lb/hr of waste) x (Btu/lb of waste)}}{\text{(cu ft of primary chamber volume)}}$$

An optimum heat-release value is typically in the range of 15,000 to 25,000 Btu per cubic foot.

To maintain the design heat-release rate, less waste can be loaded as heating values of the waste increase. Thus, less Type 0 waste, which has a heating value of 8,500 Btu/lb, can be burned per hour than Type 1 waste, which has a heating value of 6,500 Btu/lb. As moisture content increases substantially, however, the use of auxiliary fuel needed to vaporize and superheat high-moisture-content wastes limits effective incinerator capacity. Therefore, although Waste Types 3 (garbage) and 4 (animal solids and organic wastes) have lower heating values than Waste Types 0 and 1, incinerator capacity ratings are reduced when these high-moisture-content wastes are incinerated (see Figure 4-6).

Burning rate, the other criterion used for designing primary chambers, basically establishes the size of the hearth area in the primary chamber. The maximum recommended pounds of waste that should be loaded per square foot of hearth area per hour for each type of waste have been determined empirically and are shown in Table 4-3.

Note that when incinerator systems are evaluated and rated, burning rate is not the same as charging or loading rate. Either term may be used by a manufacturer to rate a system. Burning rate is the amount of waste that can be burned per hour, whereas charging or loading rate is the amount of waste that can be loaded per hour. Loading rates often exceed burning rates if the system operates less than 24 hours per day.

Secondary Combustion Chamber

Secondary combustion chambers basically are sized and designed using the three Ts (time, temperature, and turbulence). These factors, which are used to effect complete

Table 4-1. Incinerator Institute of America Waste Classifications

Classification of Wastes: Type	Classification of Wastes: Description	Principal Components	Approximate Composition % by Weight	Moisture Content %	Incom-bustible Solids %	Btu Value/Lb of Refuse as Fired
0	Trash	Highly combustible waste, paper, wood, cardboard cartons, including up to 10% treated papers, plastic or rubber scraps; commercial and industrial sources	Trash 100%	10%	5%	8,500
1	Rubbish	Combustible waste, paper, cartons, rags, wood scraps, combustible floor sweepings; domestic, commercial and industrial sources	Rubbish 80% Garbage 20%	25%	10%	6,500
2	Refuse	Rubbish and garbage; residential sources	Rubbish 50% Garbage 50%	50%	7%	4,300
3	Garbage	Animal and vegetable wastes, restaurants, hotels, markets; institutional, commercial and club sources	Garbage 65% Rubbish 35%	70%	5%	2,500
4	Animal solids and organic wastes	Carcasses, organs, solid organic wastes; hospital, laboratory, abattoirs, animal pounds and similar sources	100% animal and human tissue	85%	5%	1,000

Source: Reference 23.

combustion of the flue gases from the primary chamber, are interdependent. For example, a secondary chamber designed for very high turbulence and short retention times often can achieve performance equal to that of a chamber designed for less effective turbulence and longer retention times. Regulatory requirements, however, often dictate retention times and combustion temperatures.

Retention times are calculated by dividing the secondary chamber volume by the volumetric flue-gas flow rate. The gas flow rate, which can be calculated or measured, is a function of waste type, combustion air quantities, and operating temperatures. In practice, gas flow rates vary widely and frequently.

Of the three Ts, temperature is the easiest to control. Temperature control is achieved by modulating combustion air, the amount of auxiliary fuel used, the rate at which waste is fed to the incinerator, and the type or composition of the waste. The amount of retention time is built into the size of the incinerator and is fixed. Turbulence also is a function of incinerator design and can be revised only slightly within limits.

Turbulence is effected mechanically (for solids) and aerodynamically (for gases). Types of equipment that produce mechanical turbulence include hand pokers, grates, rams, rotary kilns, and pulse hearths. Aerodynamic turbulence is achieved using such features as high-velocity air injection, baffles and restrictions, directional changes, cyclonic flow, and suspension firing.

4.1.4.3 Capacity Determination

Three factors affect the selection of incineration system capacity: waste generation rates; waste types, forms, and sizes; and operating hours. The effect of waste type on heat-release rates and thus on incinerator capacity has been discussed above. The effects of waste generation rates, waste form and size, and operating hours are discussed below.

Waste generation rates must be estimated or calculated to determine optimum capacity. When computing rates, waste managers should consider not only averages, but peaks, ranges, and fluctuation cycles as well. The most accurate method of determining this information is to institute a 2-week or longer weighing program. When waste generation is estimated using numbers and volume of containers hauled offsite, the variations in waste density and the possibility of partial loading of containers can lead to gross errors in waste generation rates. When waste generation rates are grossly underestimated, the selected incineration capacity may be too small, which could result in system overloading and concomitant operational problems. When waste generation rates are overestimated, the selected incinerator capacity may be too large and reduced operating hours may be required, leading to other types of problems, such as waste handling problems or insufficient heat recovery to justify the costs of operating the system.

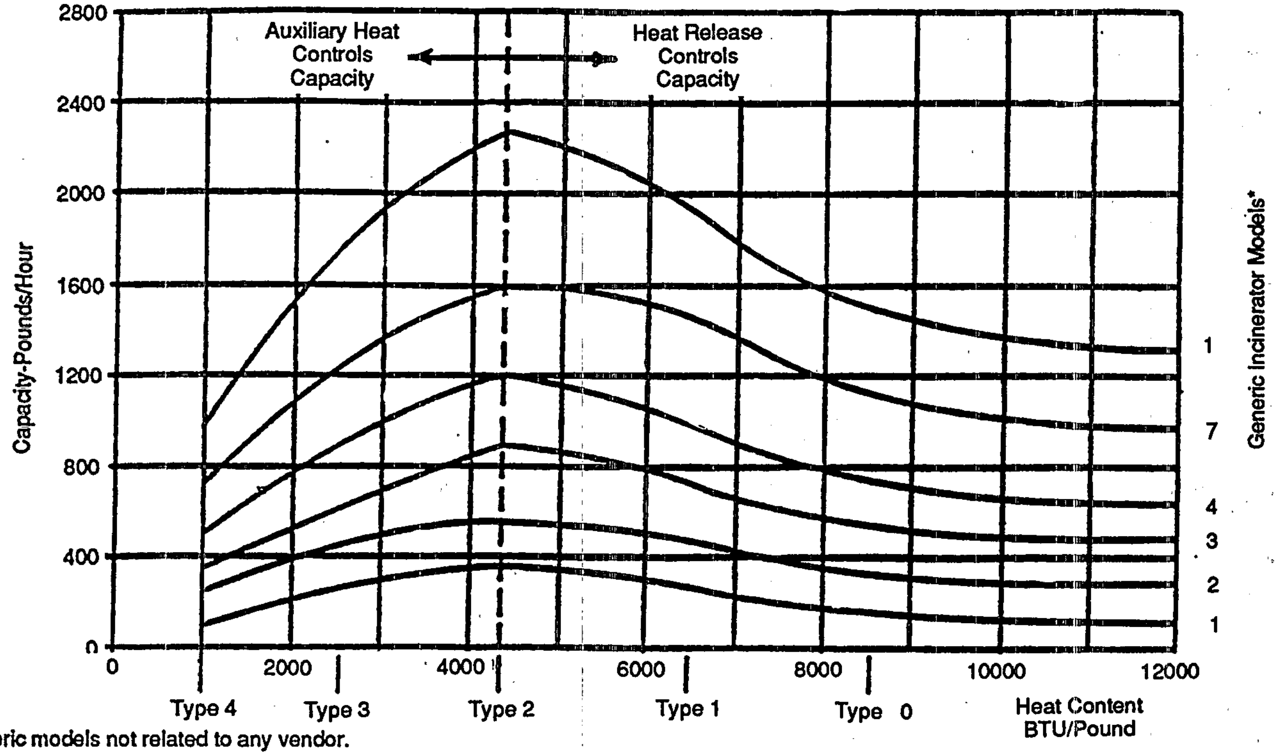
Waste type and forms also affect incinerator capacity. Densely packed material has an effective incinerability factor much less

Table 4-2. Waste Data Chart*

Material	Btu Value/Lb as Fired	Weight in Lbs/Cu Ft (Loose)	Weight in Lbs/Cu Ft	Content by Weight in %	
				Ash	Moisture
Type 0 Waste	8,500	8-10		5	10
Type 1 Waste	6,500	8-10		10	25
Type 2 Waste	4,300	15-20		7	50
Type 3 Waste	2,500	30-35		5	70
Type 4 Waste	1,000	45-55		5	85
Acetic acid	6,280		65.8	0.5	0
Animal fats	17,000	50-60		0	0
Benzene	18,210		55	0.5	0
Brown paper	7,250	7		1	6
Butyl sole composition	10,900	25		30	1
Carbon	14,093		138	0	0
Citrus rinds	1,700	40		0.75	75
Coated milk cartons	11,330	5		1	3.5
Coffee grounds	10,000	25-30		2	20
Corn cobs	8,000	10-15		3	5
Corrugated paper	7,040	7		5	5
Cotton seed hulls	8,600	25-30		2	10
Ethyl alcohol	13,325		49.3	0	0
Hydrogen	61,000		0.0053	0	0
Kerosene	18,900		50	0.5	0
Latex	10,000	45	45	0	0
Linoleum scrap	11,000	70-100		20-30	1
Magazines	5,250	35-50		22.5	5
Methyl alcohol	10,250		49.6	0	0
Naphtha	15,000		41.6	0	0
Newspaper	7,975	7		1.5	6
Plastic coated paper	7,340	7		2.6	5
Polyethylene	20,000	40-60	60	0	0
Polyurethane (foamed)	13,000	2	2	0	0
Rags (linen or cotton)	7,200	10-15		2	5
Rags (silk or wool)	8400-8,900	10-15	2	5	
Rubber waste	9,000-11,000	62-125	20-30	0	
Shoe leather	7,240	20	21	7.5	
Tar or asphalt	17,000	60	1	0	
Tar paper (1/3 tar-2/3 paper)	11,000	10-20	2	1	
Toluene	18,440		52	0.5	0
Turpentine	17,000		53.6	0	0
1/3 wax-2/3 paper	11,500	7-10		3	1
Wax paraffin	18,621		54-57	0	0
Wood bark	8,000-9,000	12-20	3	10	
Wood bark (fir)	9,500	12-20	3	10	
Wood sawdust	7,800-8,500	10-12	3	10	
Wood sawdust (pine)	9,600	10-12	3	10	

*This chart shows the various Btu values of materials commonly encountered in incinerator designs. The values given are approximate and may vary based on their exact characteristics or moisture content.

Source: Reference 23.



*Generic models not related to any vendor.

Figure 4-6. Incinerator capacities as a function of waste types.
Source: Reference 29.

Table 4-3. Maximum Burning Rate (lbs/sq ft/hr) of Various Type Wastes

Capacity (lbs/hr)	Logarithm	Type 1 Waste	Type 2 Waste	Type 3 Waste	Type 4 Waste
		Factor 13	Factor 10	Factor 8	No Factor
100	2.00	26	20	16	10
200	2.30	30	23	18	12*
300	2.48	32	25	20	14*
400	2.60	34	26	21	15*
500	2.70	35	27	22	16*
600	2.78	36	28	22	17*
700	2.85	37	28	23	18*
800	2.90	38	29	23	18*
900	2.95	38	30	24	18*
1000	3.00	39	30	24	18*

*The maximum burning rate in lbs/sq ft/hr for Type 4 waste depends to a great extent on the size of the largest animal to be incinerated. Therefore, whenever the largest animal to be incinerated exceeds 1/3 the hourly capacity of the incinerator, use a rating of 10 lbs/sq ft/hr for the design of the incinerator.

Maximum burning rate (BR), expressed in lbs/sq ft/hr, for Type 1, 2, and 3 waste is calculated using factors as noted in the formula below:

BR = Factor for type waste x log of capacity/hr

where: Type 1 waste factor = 13
Type 2 waste factor = 10
Type 3 waste factor = 8

For example, assuming Type 1 waste and an incinerator capacity of 100 lbs/hr for this waste type, BR is calculated as follows:

BR = 13 (factor for Type 1 waste) x Log 100 (capacity/hr) = 13 x 2 = 26 lbs/sq ft/hr

Source: Reference 23.

than that of loosely packed material of the same type. Also, waste with high ash-formation tendencies may have lower burning rates, and highly volatile wastes may require burning-rate reductions to avoid smoking problems.

The physical size of individual waste items is also an important factor in incinerator capacity selection. One rule of thumb is that an average incinerator waste load should weigh approximately 10 percent of the rated, hourly capacity of the system.

Finally, the capacity of the incinerator also depends on the number of hours it will be operating. For example, controlled-air incinerators with manual ash cleanout usually are limited to a maximum of 12 to 14 hours of operation per day.

4.1.5 Incineration Systems and Equipment

Incinerators typically are only one of the many components required for a complete incineration system. Other components include waste and ash handling equipment, burner and combustion air-blower systems, flue-gas handling systems, controls and instrumentation, and, in many installations, air pollution control systems and waste-heat recovery systems. These systems are discussed in the sections below, except for air pollution control systems, which are discussed in Section 4.2.

4.1.5.1 Waste Handling and Loading Equipment

Waste handling systems include equipment to collect and transport waste, storage equipment, pretreatment equipment (such as shredders), and incinerator loading equipment. Not all incinerators have loading equipment; small incinerators may use manual loading. Several states, however, now require mechanical loaders on all incinerators because of the numerous advantages of these systems.

The primary advantage of mechanical waste loaders is that heat, flames, and combustion products are prevented from escaping the incinerator, thus protecting personnel and preventing fires. Also, ambient air infiltration into the incinerator is minimized by mechanical loaders. Air infiltration affects combustion conditions and can lead to lower furnace temperatures, smoking, increases in auxiliary fuel use, and accelerated refractory deterioration. Mechanical loaders also facilitate charging incinerators with small batches of waste at regulated intervals, thus providing stabilized combustion conditions and protecting against overcharging.

Most incinerators are equipped with a hopper/ram-type charging system (see Figure 4-7), in which waste is loaded into a charging hopper, the hopper cover is closed, a primary chamber fire-door opens, and a charging ram then pushes the waste into the incinerator. The loading hopper of hopper/ram systems is sized for volume on the basis of waste type, waste container size, method of loading the hopper, and incinerator capacity. Incorrect sizing of hoppers could lead to waste spilling or undercharging or overcharging the incinerator. Most hopper/ram assemblies are equipped with a water system to quench the face of the charging ram after each loading cycle to prevent burning waste from sticking to the ram and igniting new waste

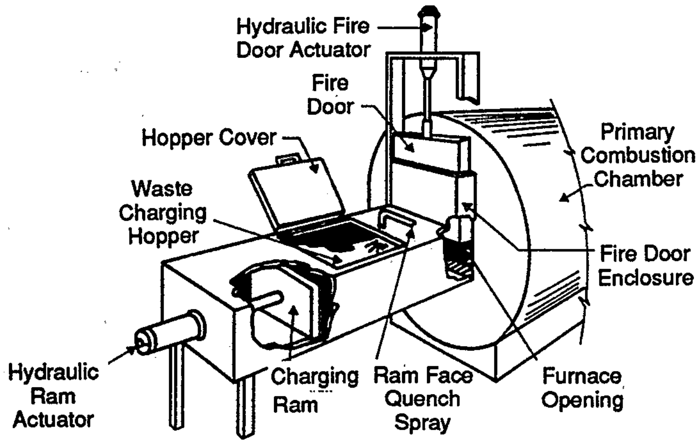


Figure 4-7. Hopper/ram mechanical waste-feed system.
Source: Reference 8.

as it is loaded into the hopper. Hoppers also may be equipped with flame scanners and alarms, fire spray systems, or emergency override switches that allow hopper contents to be pushed immediately into the incinerator.

One rotary-kiln manufacturer uses an auger feeder (see Figure 4-8). The feeder not only loads the incinerator but shreds the waste to a size that can be accommodated by the incinerator. As discussed, this type of loading or pretreatment system typically is required on small-capacity rotary kilns burning medical waste.

Various systems and equipment, including conveyors, cart dumpers, and skid-steer tractors, are used to feed incinerator loading systems mechanically. A cart-dumper is a device for lifting and dumping waste carts into the hopper of loading systems. This type of system is used in many installations because it reduces waste handling and eliminates the need for intermediate storage containers and additional waste-handling equipment.

4.1.5.2 Residue Removal and Handling System

Most small incinerators and many older incinerators must be cleaned out manually. Manual cleaning is undesirable or unacceptable for several reasons:

- Difficult labor requirements.
- Hazards to operating personnel from exposure to heat, flaming materials, glowing ashes, etc., and aesthetic, environmental, and fire safety problems when handling hot ashes outside the incinerator.
- Daily cool-down and start-up cycles that consume auxiliary fuel, reduce operating hours, and reduce life of incinerator refractories.
- Possible regulatory restrictions.

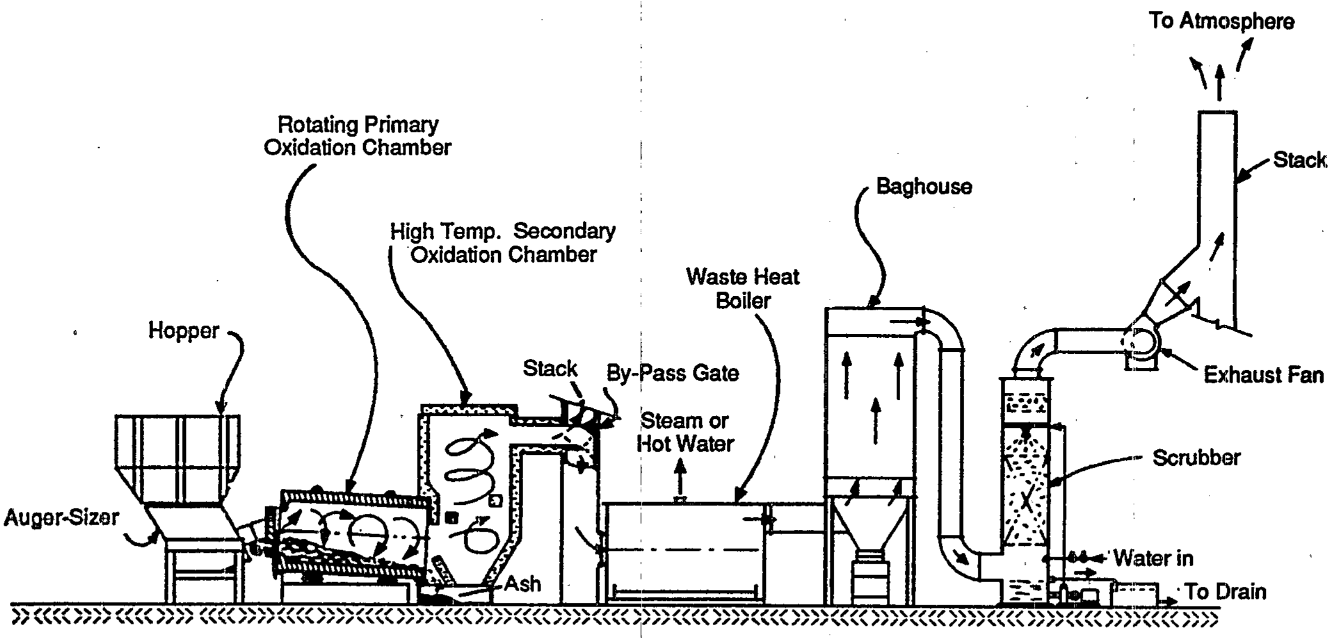


Figure 4-8. Rotary kiln with auger feed.
Source: Reference 8.

Large-capacity, multiple-chamber incinerators use mechanical grates, or stokers, to facilitate ash removal. Rotary-kiln incinerators use the rotation of the kiln to remove ashes. Automatic ash removal from controlled-air incinerators, however, has been difficult to achieve. Early ash-removal systems for controlled-air incinerators were designed to use an opening floor in the primary chamber to drop ashes into a container or vehicle, but these systems had serious operating problems. Other early controlled-air incinerator designs used rams to push the ash out a discharge door, but these systems also had only limited success.

The most successful ash-handling system on controlled-air incinerators, found on almost all modern systems, uses the charging ram of the hopper/ram loading system to push ash through the chamber to the discharge chute for removal. Large controlled-air incinerators use internal transfer rams to help push ashes through the chamber, whereas smaller units might use only the waste-charging ram to move the ash across the hearth. A continuous-duty controlled-air incinerator with ash transfer rams is illustrated in Figure 4-9. When the ash reaches the end of the hearth, it drops off the end of the hearth into a discharge chute and into either an empty ash container or a water pit where the ash is quenched. The ash is allowed to drain and then is discharged into a collection container. An innovative method for ash removal on controlled-air incinerators uses a "pulse hearth" to transfer ashes. With this system, the entire floor of the chamber pulses, and as it does so, it causes the ash to move across the floor to the discharge chute.

Two methods are used to remove ash from the incinerator after it has been discharged from the primary chamber:

- A semiautomatic system using ash collection carts, which are located within an air-sealed enclosure beneath the drop chute. The collected ashes are sometimes sprayed with water to quench them slightly and to suppress dust. Loaded ash carts then are removed manually and replaced with empty carts. Once the ashes are cooled, ash carts are emptied into a larger container for offsite disposal or are brought directly to the landfill.
- A fully automatic system using a water quench trough and ash conveyor. This system operates continuously, bringing quenched ashes to a container or vehicle via the conveyor, which may be a drag, or flight, conveyor, or a "backhoe" or "scoop" design. The conveyor system must be properly designed to withstand severe service.

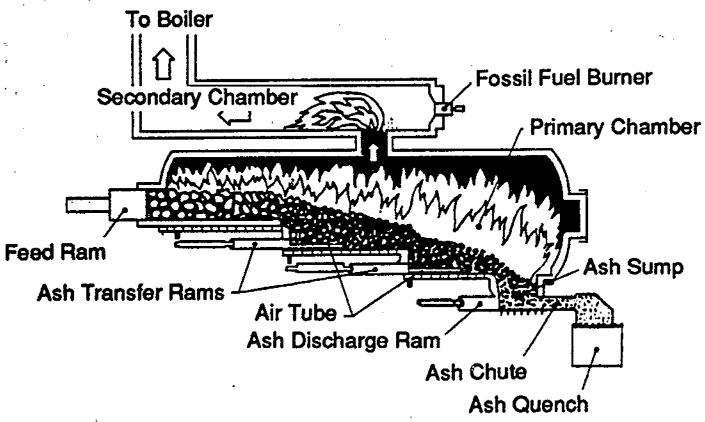


Figure 4-9. Incinerator with step hearths and automatic ash removal. Source: Reference 4.

4.1.5.3 Waste-Heat Recovery

Waste-heat recovery often is used to reduce incinerator operating costs by providing useful energy in the form of steam or hot water. Some waste-heat recovery systems are installed not only because of favorable economics, but because of local regulatory requirements. The costs of some waste-heat recovery installations are justified when the facility receives a Department of Energy matching grant. Furthermore, a waste-heat recovery system often is justified partially because it provides a substantial reduction in air pollution control system costs and requirements by lowering flue-gas temperatures.

Several types of waste-heat recovery boilers are used on incinerators. Firetube boilers, both single and multipass, are used most frequently because of their simplicity and low cost. One controlled-air incinerator manufacturer exclusively uses a single-drum watertube-type boiler. Watertube boilers, however, typically are used only on large-capacity systems requiring high steam pressures. Waterwall heat-recovery systems are constructed with radiant sections or watertubes in the primary chamber of the incinerator, and these waterwall sections usually are installed in series with a convective-type waste-heat boiler. This type of heat-recovery system is used on very-large-capacity incinerators.

Other equipment may be part of the heat-recovery system. Some facilities use supplemental fuel-fired boilers to generate steam when the incinerator is not operating. Automatic soot-blowing systems may be installed to increase online time and recovery efficiencies.

Heat-recovery efficiencies realistically range from 50 to 60 percent, although claims have been made for higher efficiencies. The energy recovered is basically a function of the flue-gas mass flow rate and inlet and outlet temperatures. Inlet temperatures usually are limited to about 2,200°F, and outlet temperatures are limited by the flue-gas dewpoint temperature (usually about 300° to 350°F) to prevent condensation and corrosion of heat-exchanger surfaces. Usually about 3 to 5 pounds of steam can be recovered per pound of typical medical waste burned, but the economics of the heat-recovery system depend on the ability of the facility to use the recovered energy. If only a portion of the steam can be used, heat recovery may not be cost effective.

Waste-heat boilers (and air pollution control systems) must be equipped with bypass systems to divert flue gases away from the boiler, directly to a stack (see Figure 4-10). The diversion systems may include a dump stack upstream of the boiler or a bypass breaching connection between the incinerator and the stack. Isolation dampers or stack lids are included on modern, well-designed bypass systems. Without such dampers or lids, hot flue gases can bypass the boiler, or ambient air can dilute gases to the boiler. Isolation dampers thus substantially improve heat-recovery efficiencies.

Some incinerator designs incorporate air-preheating systems. These systems consist of jacketing around the primary or secondary chamber through which combustion air is pulled. The combustion air is heated by as much as several hundred degrees, thus reducing auxiliary fuel usage by as much as 10 to 15 percent. The jacketing on some systems also helps reduce or limit incinerator skin temperature to within regulatory limits.

4.1.5.4 Other Incinerator Components and Appurtenances

Other incinerator components and features that require proper attention and design include incinerator burning surfaces;

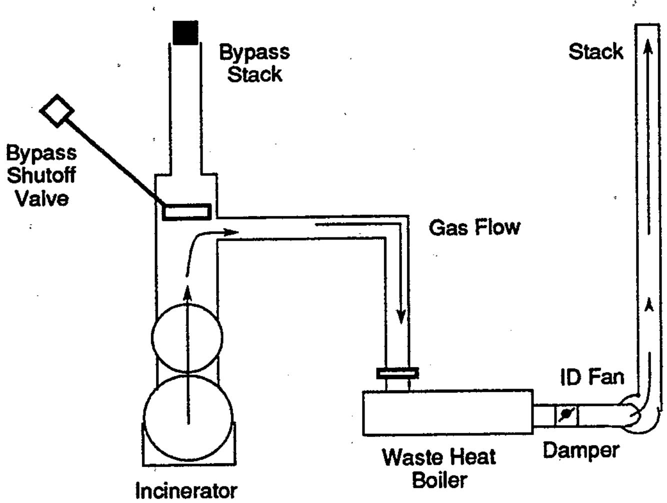


Figure 4-10. Incinerator with waste-heat boiler bypass stack. Source: Reference 8.

refractories and linings; auxiliary fuel equipment and burners; flue-gas handling components, such as breechings and stacks; and controls and instrumentation. Each of these is discussed briefly below.

- Incinerator burning surface—The burning surface may include hot or cold refractory hearths, fixed or moving grates, or combinations of these surfaces.
- Refractories—Refractories are heat-resistant materials that provide containment of the combustion process. They also radiate heat back into the incinerator; support the burning waste and ash; and protect personnel, the environment, and surrounding areas. Refractories may be castables or preshaped bricks.
- Incinerator linings—Incinerator linings typically include the refractory, an insulation layer, steel casings, and, in some cases, an air jacketing or shrouding.
- Auxiliary fuel—Auxiliary fuel systems are used to ignite the waste, preheat the incinerator chamber, maintain high temperatures, and control burn-down. Ignition, preheating, and the burning of low-energy waste are the functions of these systems in the primary chamber. In the secondary chamber, auxiliary fuel is used for preheating, maintaining high temperatures, and providing a hot flame for improved burnout of organics. Burner controls can range from fully manual to fully automatic. Modern systems integrate burner and air-blower controls for improved efficiencies.
- Flue-gas handling—Flue-gas handling equipment includes high- or low-temperature breeching; main and bypass stacks; dampers; and draft inducers, or induced-draft fans.
- Stacks—Depending on operating temperature and flue-gas conditions, stacks may be lined with high-temperature refractory or constructed of fiberglass-reinforced plastic for low-temperature operation if handling saturated gases from wet scrubbers. They also may be built with masonry or other special construction materials. Stack heights are determined by the heights of surrounding buildings or topography, building and fire codes, draft requirements, entrapment avoidance, and/or ambient air quality and dispersion modeling. Stack accessories may include an exit cone, spark arrester, test ports (with platform), ladder with safety cage, lightning protection, aircraft warning lights, cleanout door, and drain.
- Incinerator draft controls—Incinerator draft may be natural, forced, induced, or balanced. Draft controls include barometric dampers, modulating dampers, and variable-speed fans.
- Combustion controls—Combustion controls provide automatic integrated management and control of waste charging operations, burner operations, combustion air supply, and draft.
- Control and instrumentation (C&I) systems—These systems include mechanical/electrical systems or solid-state programmable controller systems for centralized combustion control, monitoring, and integrated operation of all system components and equipment.
- Monitoring and recording equipment—Temperatures typically are monitored in the primary and secondary chambers, at the boiler inlet and outlet, and at the air pollution control equipment inlet and outlet. Pressures usually are monitored at the primary chamber as draft, in the air pollution control equipment as pressure drop, and in the combustion air manifolds. Typically, scrubber water pressures also are monitored. Flows usually are monitored for scrubber water and blowdown, auxiliary fuel, and recovered steam. Scrubber pH is monitored, as are many types of emissions (see Section 4.2). Devices for continuously monitoring carbon monoxide, oxygen, and sometimes hydrogen chloride are known as a continuous emissions monitoring system (CEMS).

4.1.6 Special Incineration Applications

Medical waste incinerators sometimes are used to incinerate low-level radioactive waste or chemical waste, which may include hazardous waste. A number of special considerations apply to incinerators in which these types of wastes are burned.

Most chemical wastes burned in medical waste incinerators are solvents burned as fuels with solid waste. A simple method for incinerating these wastes is to inject them into the flame of an auxiliary fuel burner using an atomizer nozzle. Larger incinerators may use special, packaged burners designed to fire solvents. These burners may handle solvents exclusively, or may be able to handle fuel oils when solvents are unavailable. Most solvent firing occurs in primary chambers to assist in burning the waste and to utilize secondary chamber volumes fully. Injectors and burners must be located so that solvents do not impinge on furnace walls or on other burners to avoid poor combustion or emission problems.

Alternatively, depending on incinerator capacity and design, small amounts of chemicals sometimes can be loaded in bottles or vials without affecting incinerator operations. When large numbers of chemical containers are burned, however, severe operating problems may ensue. These problems can include rapid, uncontrolled combustion, leading to smoking and excessively high temperatures, and melting and slagging of glass containers, which can damage refractory materials and plug air-supply ports.

In addition to the firing system, a properly designed chemical-waste handling system also must be used when chemical wastes are incinerated. The system should include a receiving and unloading station, a storage tank, a pump set to feed the injector or burner, appropriate spill containment (diking) and protection, monitoring devices, and safety protection devices. Most of this equipment should be located in a separate, fire-rated room with special ventilation and explosion-proof electrical fixtures.

Federal, state, and local regulations must be followed when transporting, handling, storing, and burning chemical waste. If the waste is designated as a hazardous waste under state or federal regulations (see Section 2.3.1.1), the incinerator must be permitted in accordance with RCRA requirements (Part B permitting), trial burn tests (which are very costly) must be run, and additional, costly, continuous monitoring and control equipment is required. Part B permitting requirements include development of waste sampling and analysis plans; security, closure, and contingency plans; inspections; recordkeeping; special personnel training; and liability coverage. Obtaining permits could delay incinerator startup by as much as 12 to 18 months.[6] Before an operating permit is issued, trial burns must show 99.99 percent destruction and removal efficiency (DRE), particulate emissions of less than 0.08 grain/dscf at 7 percent oxygen, and hydrogen chloride emissions of less than 4 lb/hr, or 99 percent removal.[4] One exception to these requirements is waste that is classified as hazardous only because of its "ignitability," i.e., it has a flashpoint of less than 140°F. Incinerators burning these types of ignitable wastes are not likely to be classified as hazardous waste incinerators, and thus may avoid the hazardous waste incinerator permitting process. The storage and handling of the ignitable waste, however, most likely will require a facility to obtain a Part B permit as a treatment, storage, and disposal (TSD) facility.

Incinerators burning low-level radioactive waste must have emissions that meet dose levels specified by the national emission standards for hazardous air pollutants (NESHAPs)[30] as well as those mandated by NRC regulations in 10 CFR Part 20. Some low-level radioactive wastes, however, are biomedically exempt, i.e., they exhibit radioactivity below specified limits and thus are not subject to NRC regulations. Mixed wastes, such as liquid scintillation cocktails (LSC), which are radioactive chemical solvents, must comply with both RCRA and NRC regulations.

4.2 Incinerator Emissions and Air Pollution Control Equipment

The types of incinerator emissions of concern and the emission limits often imposed on medical incinerators are summarized in this section. Strategies for controlling emissions are discussed, and the technology for achieving emissions control is summarized.

4.2.1 Incinerator Emissions

Emissions from medical waste incinerators are generated from either waste constituents, components of combustion air, or byproducts of the combustion process itself. Pollutants of concern include particulate matter, toxic metals, toxic organics, carbon monoxide, and acid gases (hydrogen chloride, sulfur dioxide, and nitrous oxides). Each of these pollutant categories is discussed below.

4.2.1.1 Particulate Matter

Particulate matter is generated when noncombustible material is suspended, when incomplete combustion of combustible materials occurs, and when vaporous materials condense. Suspension of particulate matter can occur when combustion air is added to the incinerator. If the amount of air entering the primary combustion chamber is kept to the minimum necessary, particulate entrainment will be reduced. Proper control of combustion will minimize particulate emissions from incomplete combustion. Vaporous materials condense on the surface of fine particles when combustion temperatures are high enough to vaporize some of the fuel constituents, which then cool in the flue gas. Particulate material can consist of combustibles or minerals. Combustible particulates may be char (large particles of carbonated materials such as paper that are incompletely combusted) or smoke (fine particulates). Minerals consist mostly of salts or silicates, which are not a health concern but which contribute to particulate emissions.

4.2.1.2 Toxic Metals

Toxic metals appear in emissions as particulates. The concentration of metals emissions depends on the quantity of metals in the waste material. Some metals are emitted as metal oxides in micron or submicron sizes. Other metals are volatilized and deposit on small, difficult to control particles. Metals that are thought to condense on other particles include arsenic, cadmium, chromium, nickel, lead, and zinc. As many as 12 to 14 different metals have been identified by some regulatory agencies as potential health risks when emitted from incinerators.*

4.2.1.3 Toxic Organics

Toxic organics can be combusted completely to form carbon dioxide and water; however, incomplete combustion can create new organic species (products of incomplete combustion, or PICs). Chlorine, derived from the incineration of PVC plastics, can combine with organics to form toxic chlorinated organics, such as dioxins and furans.

4.2.1.4 Carbon Monoxide

Carbon monoxide is a product of incomplete combustion and is a good measure of incinerator efficiency. Many state agencies require monitoring of carbon monoxide emissions to ensure proper operating conditions in the incinerator. Carbon monoxide production is limited when oxygen concentrations, mixing, and temperatures are adequate.

4.2.1.5 Acid Gases

Acid gases are created when nitrogen, sulfur, and chlorine are released during combustion. The acid gas of most concern in

*Doucet, Lawrence G., Doucet & Mainka, P.C., personal communication, November, 1991.

medical waste incinerators is hydrogen chloride. Hydrogen chloride is created when wastes containing chlorine, such as PVC materials, are incinerated. Sulfur also may be found in the waste stream, whereas nitrogen is a waste component and a constituent of the combustion air.

4.2.2 Regulatory Requirements for Emission Control

State regulations limiting emissions from medical waste incinerators can include emission limits on all of the pollutants of concern listed above. Many states have passed new, and increasingly stringent regulations for medical waste incinerators. These regulations often include limits on specific pollutant concentrations in stack gases, as well as limits on concentrations of toxic metals and organics in the ambient air. Furthermore, under Sections 129 and 111(b) of the Clean Air Act of 1990, EPA is developing new source performance standards (NSPS) to regulate the emissions of new medical incinerators. The pollutants to be regulated are particulate matter, acid gases, trace metals (lead, cadmium, and mercury), carbon monoxide, and organics such as dioxins and furans. EPA expects to promulgate these regulations in 1992.[31]

Some regulatory agencies establish ambient air-quality limits. To demonstrate compliance with such limits, air-quality modeling of stack gas dispersion must be performed, often as part of the permitting procedure. Stack testing is required to demonstrate compliance with limits on stack gas emissions. Ash residues also may need to be tested for constituents to demonstrate compliance with regulations.

Best available control technology (BACT) for particulate emissions is not well defined and varies from state to state. Some states define BACT for particulate emissions as 0.015 gr/dscf.[6] State designation of BACT for hydrogen chloride emissions typically is identified as a 90 percent reduction in hydrogen chloride by the air pollution control (APC) system or a concentration of 30 parts per million in the stack gas. Requirements for small systems (e.g., those handling under 200 to 500 lbs/hour) and for existing systems are usually less stringent than those for larger or new systems.[6]

4.2.3 Emission Control Strategies

Emission control begins with controlling the waste feed material. Heavy metals, chlorinated organics, and acid gas emissions all can be reduced by eliminating the use of certain materials at the institution, segregating wastes at the point of origin, or removing problem materials before incineration. For example, substituting polyethylene plastics for PVC can reduce the amount of chlorine-containing wastes incinerated, thereby reducing concentrations of chlorinated organics and hydrogen chloride. Segregation or removal of noncombustible dusts and powders (to reduce particulate matter emissions), heavy metals (such as wastes from dental clinics or laboratories), and PVC plastics would reduce the emission of many problem pollutants.

Combustion control also relates to emission control. Incomplete or poor combustion produces excess particulate matter, PICs, and carbon monoxide. Because of the variability of medical waste, incinerators must be operated flexibly, varying operating conditions as waste constituents vary. In general, combustion conditions improve with higher temperatures, well-controlled excess-air rates, flue-gas mixing or turbulence, and retention times. However, greater costs and (depending on the waste-feed composition) increased emissions of nitrous oxides and toxic metals can result from operating incinerators at higher temperatures. Not all pollutants, however, can be controlled by controlling incinerator operating parameters. Hydrogen chloride and sulfur dioxide emissions are not affected by operating conditions in the incinerator.

When feed material and combustion controls do not produce emission levels compatible with regulatory requirements, air pollution control systems must be installed. The types of air pollution control equipment, how this equipment operates to control emissions, and some of the advantages and disadvantages of each type of equipment are discussed in the following section.

4.2.4 Air Pollution Control Equipment

Many types of emission control equipment are available. Systems include wet and dry scrubbers, settling chambers, mechanical cyclones, and electrostatic precipitators. Settling chambers and mechanical cyclones do not meet new emission standards; electrostatic precipitators are far too costly for most medical waste incinerators, have problems with corrosion and fouling, and can pass large particles through the system. To date, only two basic types of systems have been used successfully on medical waste incinerators to meet the new stringent state emission limits: wet and dry scrubbers.[9]

4.2.4.1 Wet Scrubbers

Wet scrubbers are the most common air pollution control devices currently used on medical incinerators because of their low cost and ease of operation. They can be used to remove acid gases alone or acid gases and particulates.

Large liquid droplets are used to capture small particles in wet scrubbers. The droplets collect particles either by a process known as impaction or by diffusion. In impaction, large particles hit the liquid droplets, and the liquid with its captured particulates then can be removed from the system. In diffusion, very small particles are bumped by gas molecules, causing the particles to move randomly in the exhaust stream. This random movement, or diffusion, causes the particles to collide with droplets, which then are removed from the system.

Acid gases are controlled by the absorption of the gaseous pollutants in the liquid. Scrubbers that effectively remove acid gases provide a large contact area between the gas and liquid phases, provide good mixing of the two phases, and allow sufficient contact time. In addition, a basic (high-pH) mixture is added to the liquid to improve acid-gas removal.

Three types of wet scrubbers are commonly used: venturi scrubbers, packed-bed scrubbers, and spray towers. Venturi scrubbers primarily remove particulates and packed-bed scrubbers primarily remove acid gases. When these scrubbers are used together, both types of emissions can be controlled more effectively. Spray towers, which are used to control both particulates and acid gases, cannot meet the newest state regulations for particulates, so are used typically with venturi scrubbers. Other types of scrubbers used more infrequently are impingement tray, collision, ejector, and wet-ionizing scrubbers. Venturi scrubbers, packed-bed scrubbers, and spray towers are discussed below.

Venturi Scrubbers

Venturi scrubbers (see Figure 4-11) are the wet scrubbers most commonly installed on medical incinerators. A venturi scrubber consists of equipment in which a liquid is sprayed upstream from a vessel containing a converging and diverging cross-sectional area (as illustrated in Figure 4-12). The narrowest portion of the venturi is known as the throat. In this area, the gas velocity and turbulence are at a maximum. The liquid droplets are atomized by using either the shearing action of the high gas velocity in the throat or spray nozzles that force high-pressure liquid through small orifices.

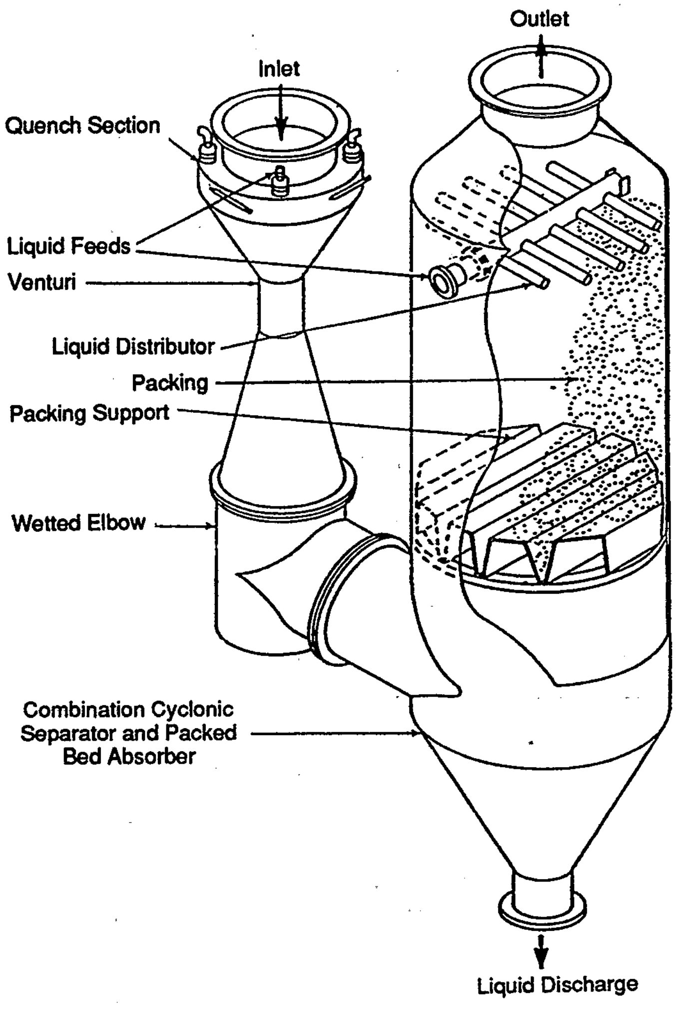


Figure 4-11. Venturi-scrubber system. Source: Reference 32.

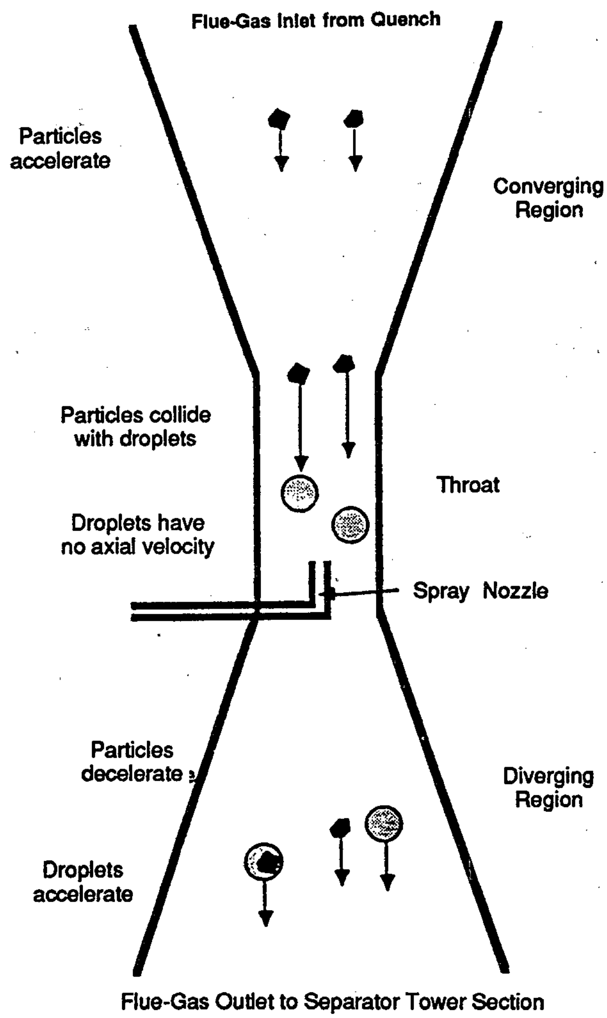


Figure 4-12. The behavior of solid particles and liquid droplets in a venturi-scrubber section. Source: Reference 33.

To attain a high collection efficiency, venturi scrubbers need to achieve gas velocities between 10,000 and 40,000 feet per minute in the throat. The design gas velocity in the throat depends on the required particulate removal efficiency and the size distribution of the particulate matter. Removal efficiencies decrease with particle size. Particulate collection efficiency, however, is correlated more directly with pressure drop across the venturi. Pressure drop, which is easily measured, influences the size of the induced draft fan required in the system, which directly affects the electrical operating costs of the system. Thus pressure drop, size of ID fan, and cost increase as particulate collection efficiency requirements increase or particle size decreases.

Following the venturi section, the saturated flue gases and droplets enter a separator, usually at the bottom of a cylindrical tower, which cyclonically separates the droplets and captured particles using centrifugal force. The top of the tower typically is equipped with a mist eliminator, a device that removes most of the remaining entrained water droplets to prevent the emission of these droplets from the scrubber system.

Packed-bed Scrubbers

Venturi scrubbers often are operated with packed-bed scrubbers, which provide additional acid-gas removal. A schematic for a venturi-scrubber system with a packed tower is shown in Figure 4-13. In the most common type of packed-bed system, the bed is vertical, and liquid (usually water with sodium hydroxide added to neutralize the absorbed acid gases) is sprayed from the top and flows downward across the bed (see Figure 4-14). The effectiveness of the acid-gas absorption is a function of the uniformity of gas velocity distribution, the surface area of the packing material, and the amount and uniform distribution of the scrubber solution. Packed-bed scrubbers are equipped with mist eliminators to capture most of the small particles created by the evaporation of the water droplets that escape from the scrubber.

Spray Towers

Spray towers typically consist of a cylindrical steel vessel containing nozzles that spray the liquid scrubbing media into the vessel (see Figure 4-15). Because very small droplets could be carried out of the scrubber, droplet particles cannot be too small, and exhaust-gas velocity must be kept low. For these and other reasons, collection efficiency is low, and the system

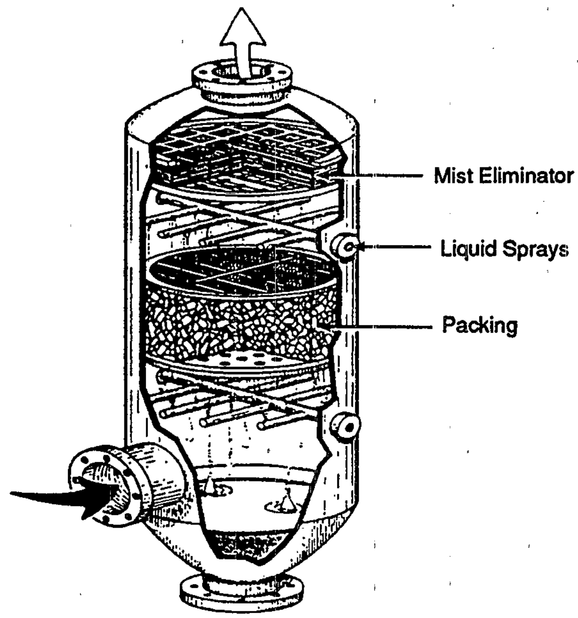


Figure 4-14. Countercurrent Packed-Tower Scrubber.
Source: Reference 8.

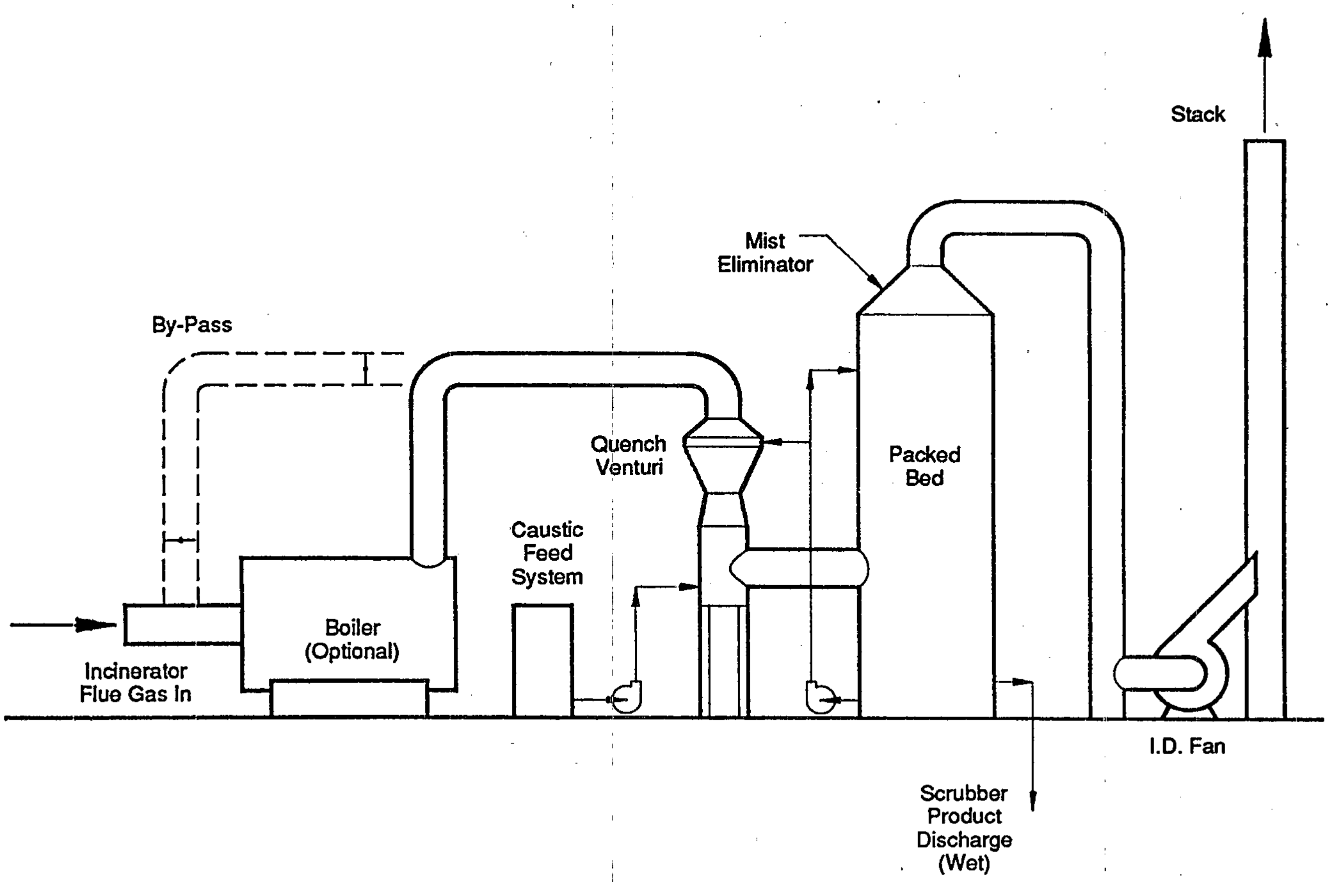


Figure 4-13. Schematic for a venturi-scrubber/packed-tower system.
Source: Reference 9.

is useful only for collecting larger particles. Because controlled-air incinerators emit relatively fine particles, these systems are unsuitable for use on these units. Spray towers are used, however, on multiple-chamber incinerators, which emit large quantities of relatively large particles.

4.2.4.2 Dry Scrubbers

Dry scrubbers generally consist of an acid-gas removal system, in which a dry alkaline substance, such as lime, is injected upstream from a particulate removal device, usually a fabric filter (baghouse). Because fabric filters do not remove acid gases and because they can be corroded by these gases, they always have been used with acid-gas removal systems. Two major types of dry-scrubber/fabric-filter systems are used: spray-dryer/fabric-filter and dry-injection/fabric-filter systems (see Figures 4-16 and 4-17). The main difference between these systems is the method of introducing the alkaline absorbent. Spray dryers use a slurry of water and lime injected through nozzles or rotary atomizers. The acid gases react with the lime in the slurry, and the water then is evaporated by the gas-stream heat until only the solid reaction particles are left for collection at the baghouse. These systems are much more expensive and complex than dry-injection systems and have not been used on medical waste incinerators. In a dry-injection system, the lime is injected directly into the gas stream to absorb acid gases. More lime is required than that for a spray dryer, and the reaction is not as efficient. These systems are sufficiently effective, however, and their relatively low cost compared to spray-dryer/baghouse systems makes them popular. Figure 4-18 contains a schematic for a dry-injection/fabric-filter system.

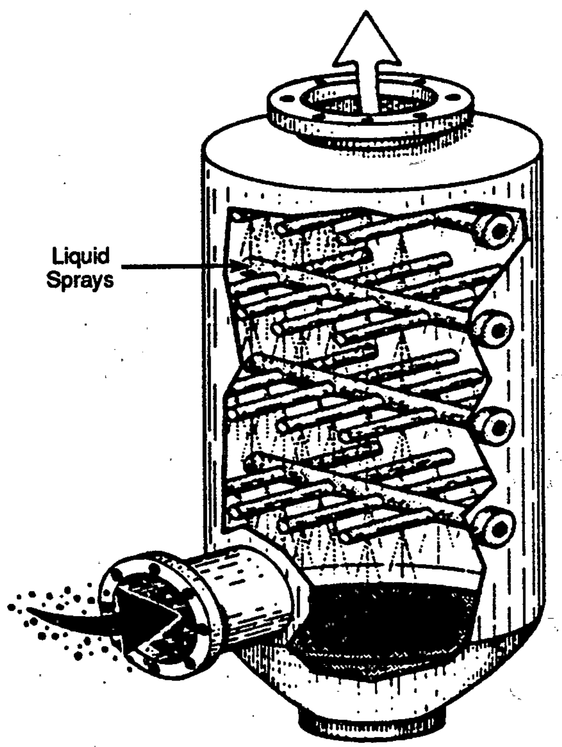


Figure 4-15. Countercurrent-flow spray tower.
Source: Reference 8.

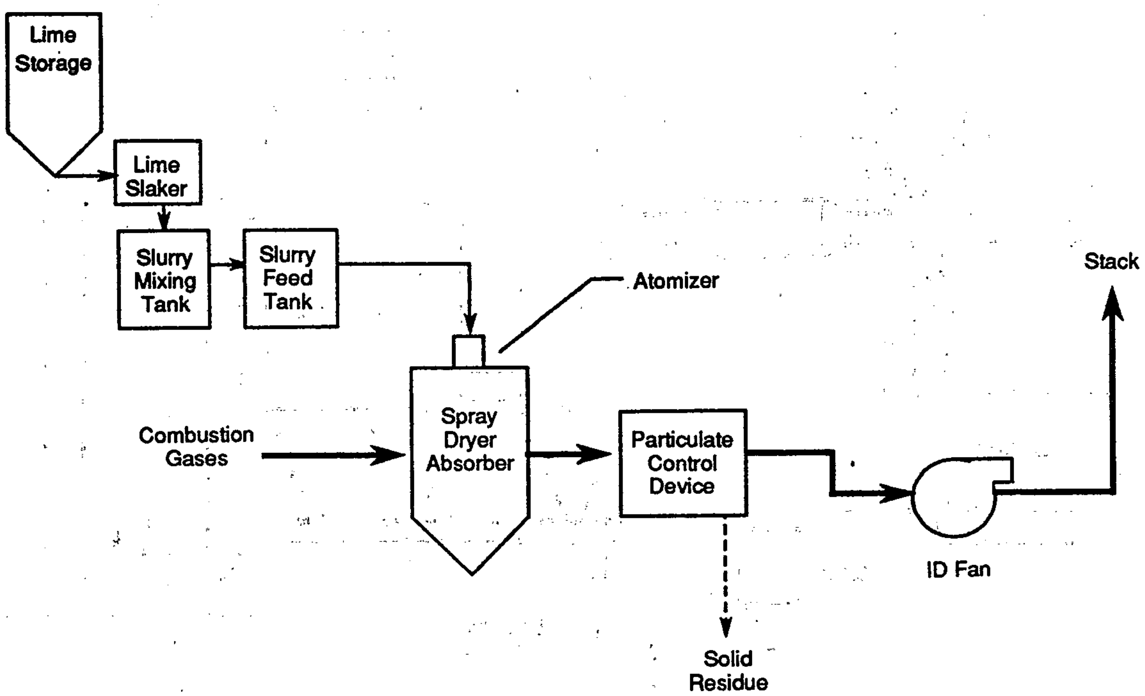


Figure 4-16. Components of a spray-dryer absorber system (semiwet process).
Source: Reference 8.

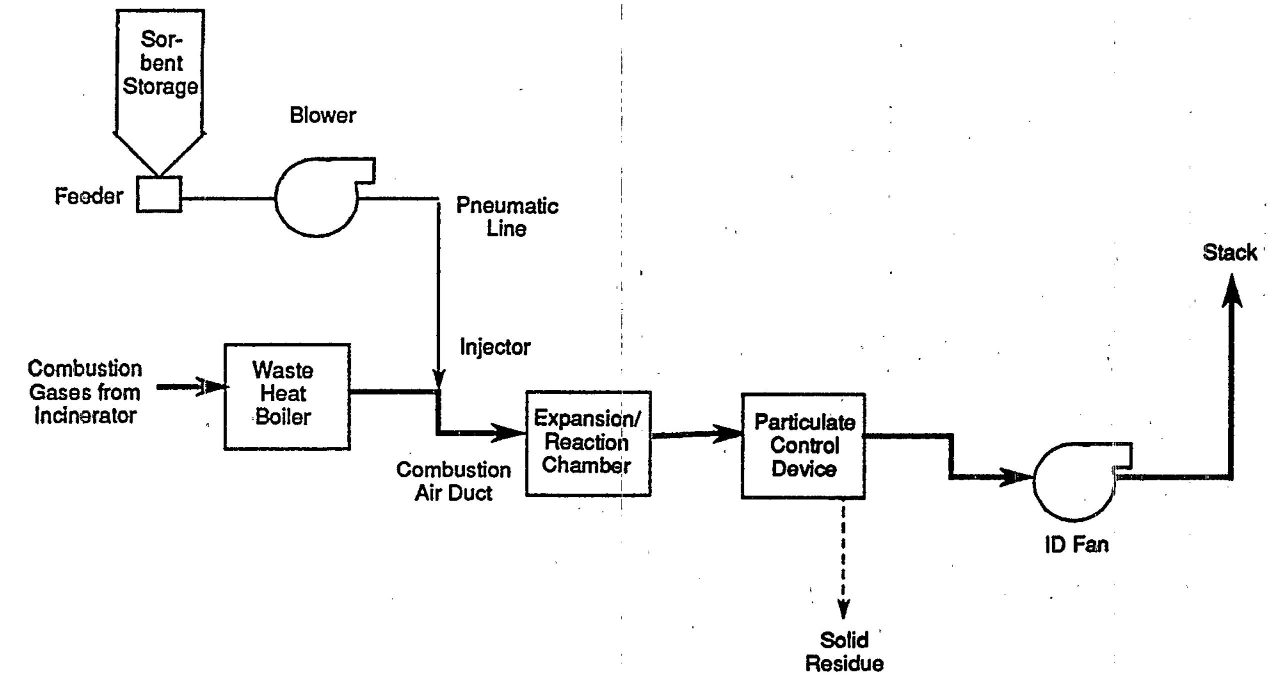


Figure 4-17. Components of a dry-injection absorption system (dry process).
Source: Reference 8.

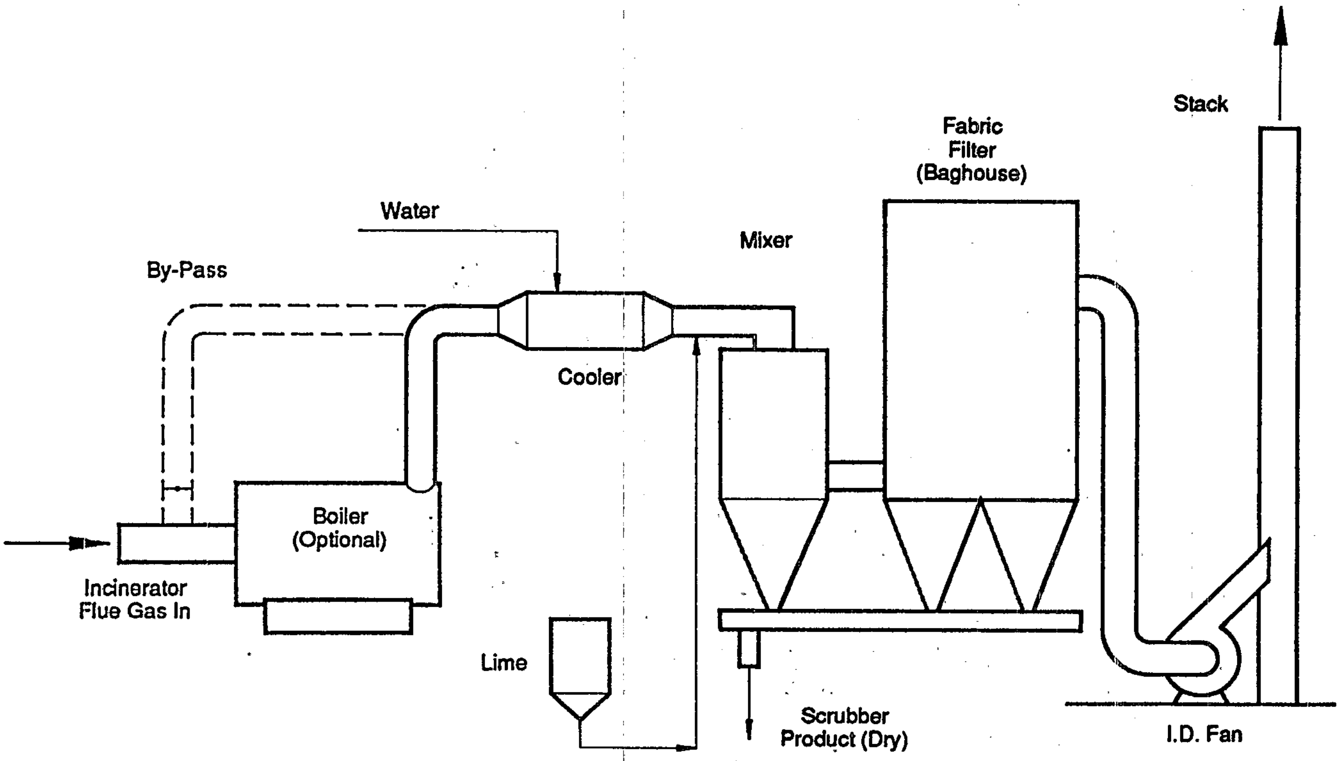


Figure 4-18. Schematic of a dry-injection/fabric-filter system.
Source: Reference 9.

The baghouse portion of the dry-scrubber system is a collection of bags constructed from fabrics, such as nylon, wool, or other material, hung inside a housing (see Figure 4-19). Bag materials must be selected carefully to withstand high flue-gas temperatures and other potentially adverse conditions. The combustion gases are drawn into the housing and pass through the bags, where the particles are retained on the fabric material while the clean gases pass through and are exhausted through a stack. The collected particles and cake buildup typically are removed from the bags by blasts of air, and the removed particles (or flyash) are stored in collection hoppers. Fabric filters are classified by the type of mechanism used to remove particles from the bags: mechanical shaker, reverse air, and pulse jet. Pulse-jet fabric filters are the only type used to date on medical waste incinerators.

Operating temperature is a critical factor in fabric-filter performance. If temperatures are too low, any remaining acid gas will condense and corrode the housing or the bags; if temperatures are too high, bags will degrade or even fail completely. A temperature of about 350°F typically is maintained to avoid both types of problems.

4.2.5 Selection of Pollution Control Devices

Data from several facilities appear to indicate that dry-scrubber systems using dry alkaline injection can achieve lower particulate emission levels than venturi scrubbers.** Venturi scrubbers, even those with mist eliminators and other special equipment, only barely may achieve the highly stringent emission limitation requirements mandated by some states, but dry-injection systems appear to be able to meet or exceed these requirements.†

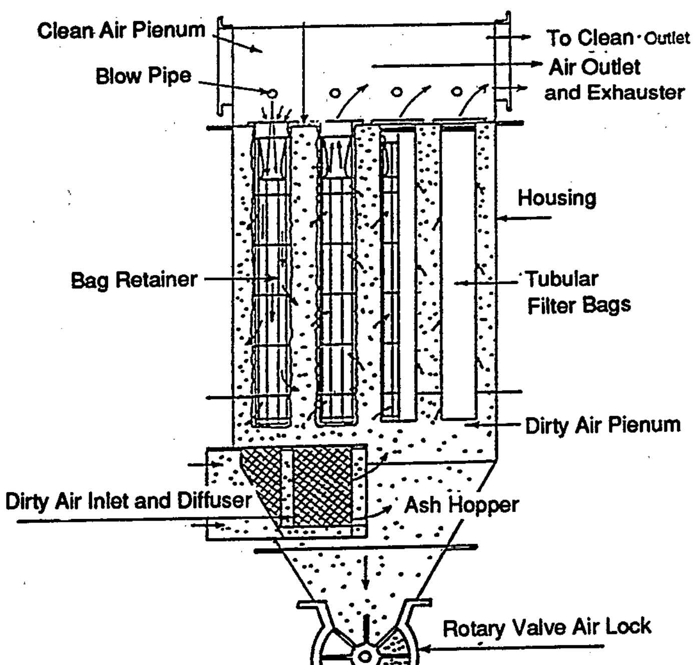


Figure 4-19. Pulse-jet-type baghouse filter.
Source: Reference 34.

Another factor in the choice of a system is the size of the facility. Small facilities may be subject to less-stringent pollution removal requirements. For this and other reasons, venturi scrubbers are the APC system of choice for smaller medical waste incinerators. Initial capital costs are lower, and venturi scrubbers are not as sensitive as fabric filters to cold-startup conditions necessitated by the cycling of batch and intermittent-duty incinerators. Furthermore, because of the sensitivity of fabric filters to high temperatures, combustion gases must be cooled by a heat-recovery system and another cooling system before they reach the fabric filter. Because waste-heat recovery often is not economical for small incinerators, this requirement adds to the cost of operating a fabric-filter system. Finally, start-up requirements for a baghouse system are more stringent. Therefore, a sophisticated control system is required, which is costly and generally not included in APC systems for small facilities. Venturi scrubbers, on the other hand, have proved themselves as appropriate systems on small medical waste incinerators because of their ability to accept hot flue gases directly and because they require no special startup considerations. Additionally, many existing facilities are required to add pollution control equipment, and venturi scrubbers require less space than dry-injection systems. Thus venturi scrubbers are easier to retrofit in most small facilities, where space quite often is restricted.

Another consideration that can affect the choice of an APC system is the cost of collecting flyash and liquid effluent disposal. Wet scrubbers produce a liquid effluent that usually is discharged directly to the sewer system, whereas baghouses produce flyash, which may be classified as either a solid waste, special-handling waste, or hazardous waste. In some cases, scrubber effluent can contain concentrations of heavy metals that potentially may exceed local sewer pretreatment standards or federal regulations. Most facilities can mix this effluent with other liquid discharges to dilute it. This procedure almost always reduces metal concentrations well below regulatory limits. Other facilities may require special spray evaporators to dry and concentrate the solids for disposal in a landfill, which greatly increases costs. Alternatively, if flyash is categorized as hazardous, disposal costs may be exorbitant. Currently, flyash seems to be classified as special handling waste, which is more costly to dispose of than solid waste, but is less costly than hazardous waste. A few medical incineration facilities have combined baghouses and wet scrubbers. These systems remove metals in the flyash, rather than in the scrubber water, and the scrubber acts to remove additional acid gas and

**Doucet, Lawrence G., Doucet & Mainka, P.C., personal communication, November, 1991.

†Recent developments and add-on features for venturi scrubbers, however, have enabled these systems to achieve particulate removal efficiencies comparable to those for dry scrubbers. (Doucet, Lawrence G., Doucet & Mainka, P.C., personal communication November, 1991.)

particulates. Combination systems are rarely required, however, and usually are much more costly than either system alone.

4.3 Other Regulatory and Permitting Considerations

Incinerator equipment and operations other than APC equipment and emissions also are regulated, and the specific state requirements vary widely. Equipment such as mechanical waste loaders, modulating burners, and enclosed ash-removal systems may be required. Incinerator operating conditions such as temperature and retention time usually are specified in regulations or permit conditions, and types of monitoring and recording activities can be required (e.g., loading rates, primary and secondary chamber temperatures, opacity, and flue-gas constituents). Requirements for operator training programs also may be included.

Many states require that air-quality modeling and health risk assessments be performed as part of the permitting process for medical waste incinerators. Air-quality modeling entails using an EPA-approved air-quality model to estimate how the stack emissions or plume affects pollutant concentrations at ambient and sensitive receptors (e.g., nearby residents). Inputs to the model include flue-gas parameters, pollutant emission rates, meteorological conditions, stack parameters, local terrain features (such as tall buildings or hills), and atmospheric dispersion parameters such as temperature gradients and wind-velocity profiles. The model produces estimates of pollutant concentrations, which must be compared to state and federal standards for ambient air-quality concentrations to show compliance with the regulations.

Where no state pollutant standards exist, the permittee may be required to perform a health risk analysis to show that the estimated pollutant concentrations will not increase significantly the risk to public health. This analysis estimates the incremental cancer risks potentially attributable to incinerator emissions. The incremental cancer risk is the estimated excess probability of contracting cancer as the result of constant 24-hour-per-day exposure to worst-case ambient pollutant concentrations over a 70-year lifetime resulting from incinerator operations. An incremental cancer risk of less than one in a million is considered an acceptable risk by most states.

The estimated maximum concentration of each pollutant of concern is multiplied by the unit risk factor associated with that pollutant to give the estimated incremental cancer risk. These unit risk factors are based on carcinogenic potency factors established by EPA's Office of Health and Environmental Assessment, which are conservative estimates of the carcinogenic risk. Because maximum lifetime exposures to maximum concentrations are assumed, and because the carcinogenic potency factors are designed to include large safety factors, the health risk assessment is a very conservative estimate of health risk.

Health risk assessments also may be required for noncarcinogenic pollutants, such as toxic metals and acid gases. Toxic metals include mercury and lead, which have known negative health effects. Acid gases, such as hydrogen chloride, are not life threatening at typical emission levels but can affect the quality of life and are potentially injurious.

Public hearings are usually a part of the permitting process. These hearings are used to address public concerns such as health risks as well as aesthetics and visibility, traffic levels, and property values. The health risk assessment can become a useful public relations tool; it can illustrate the comparative risks associated with medical waste incinerators, which in general pose incremental cancer risks of less than one in a million.

Chapter 5
Designing and Implementing Waste Management Plans

Waste management planning requires that the institution's needs for waste disposal be determined, that the proper treatment and disposal option for the facility's needs be selected and procured, and that a program of employee training be established to ensure safety and proper equipment operation. These three areas of waste management planning are reviewed in this chapter as they relate to the design and implementation of a waste management plan emphasizing onsite incineration as the chosen waste treatment option.

5.1 Designing a Waste Management Plan

Medical waste management is becoming an increasingly important issue to all types of institutions. Broadening legislation, fears of AIDS and other blood-borne diseases, tightening policies by institutions with public image concerns, and fears of liability all contribute to the need for institutions to consider carefully their existing waste management practices. Additionally, increasing limitations on landfill space and other offsite disposal options further require institutions to evaluate, redesign, and/or develop an integrated waste management program.

A waste management program should address four major concerns: the safety and health of employees who must handle potentially infectious waste; existing and proposed federal, state and local regulations and accreditation requirements; offsite liabilities and risks of exposing offsite populations to infectious waste; and costs of treating and disposing of infectious and other waste generated by the institution.[4]

In meeting these concerns, the waste management program will be most effective if it is manageable and enforceable, allows for some flexibility, ensures compliance with all regulations and standards, ensures the health and safety of workers and others, preserves environmental integrity, and promotes a cost-effective solution to the institution's waste management needs.

5.1.1 Waste Disposal Evaluations

The early steps of designing a waste management plan include the waste disposal evaluations and the option selection processes outlined in Chapter 3. These evaluations determine waste types, sources, quantities, and other important parameters needed to select the waste treatment and disposal options that can meet the institution's needs.

If the incineration option is selected, additional waste characterizations may be required. Heating values for the types of waste to be incinerated must be determined. Heating values can be calculated based on an assumed average IIA waste type (see Section 4.1.4.2) or on individual waste components. In some cases, laboratory analysis can be used. A proximate analysis can be used to determine the weight percentage of moisture, volatiles, fixed carbon, and noncombustibles in the waste. An ultimate analysis can be undertaken to determine the weight percentages of elemental constituents of carbon, hydrogen, oxygen, nitrogen, chlorine, sulfur, metals, etc. The physical form of the waste also must be considered; that is, whether the waste is loosely or highly compacted and whether large items, such as large animal carcasses, must be incinerated (see Section 4.1.4.3). All these factors will affect significantly the size of the incinerator needed at the institution, as well as which emission controls may be most suitable.[2] Incorrect characterization of the waste can lead to operating problems and/or the need to reduce system capacities. Some of the deficiencies of waste characterizations and their effect on capacity are summarized in Table 5-1.

5.1.2 Incineration Option Selection

Various options that often need to be evaluated and selected for an incineration system and design include parameters such as operating period, ash removal, waste-heat recovery, monitoring and recording, degree of automation, and redundancy. When selecting incineration options or add-ons, the planner also may want to consider whether it would be viable or cost-effective to coincinerate flammable solvents, chemotherapy chemicals in bulk or trace amounts, or low-level radioactive wastes with medical wastes. Site-selection criteria also must be evaluated for an incinerator. Such criteria include how large a space is available, how accessible the location will be, what types of waste and residue handling are most appropriate and can be accommodated, how flue gases will be handled, how to deal with visibility and aesthetics, how acceptable the installation will be to the surrounding inhabitants, and what types of operations will be performed.

5.2 Selecting and Procuring an Incineration System

Not all incinerators perform up to expectations. Incinerator systems provide good performance only if their design and

Table 5-1. Waste Characterization Data Deficiencies Necessitating System Capacity Reductions

Actual Waste Characterization Deviations from Selected "Design" Values	Typical Examples	Basic Reasons for Reduced Capacities*
Heating values (btu/lb) excessive	Greater concentrations of paper and plastic components (or less moisture) than those originally identified and specified	Incinerator volumetric heat release rates (Btu/Cu ft/hr) exceed design limits**
Moisture concentrations excessive	Greater concentrations of high water-content wastes, such as animal carcasses or food scraps (garbage), than those originally identified and specified	Increased auxiliary fuel firing rates and additional time required for water evaporation and superheating
Volatiles excessive	Greater concentrations of plastic (such as polyethylene and polystyrene) or flammable solvents than those originally identified and specified	Rapid (nearly instantaneous) releases of combustibles (volatiles) in large quantities along with excessively high temperature surges
Densities excessive	Computer printout, compacted waste, books, pamphlets, and blocks of paper	Difficulties in heat and flames penetrating and burning through dense layers of waste
High ash-formation tendencies	Animal bedding or cage wastes, wood chips, shavings or sawdust	Ash layer formation on surface of waste pile insulates bulk of waste from heat, flames, and combustion air

*Failure to reduce capacities, or hourly waste loading rates, to accommodate indicated deviations would most likely result in other more serious operational problems.

**Based on accepted, empirical values, primary chamber heat release rates should be in the range of 15,000 to 20,000 Btu/cu ft/hr.

Source: Reference 6.

operation satisfy specific user objectives such as burning capacity, destruction, environmental integrity, and online reliability. Performance problems can range from minor nuisances to major disabilities, and corrective measures can range from simple adjustments to major modifications and even to total abandonment. According to several estimates approximately 25 percent of all medical waste incineration systems installed within the last 10 years do not operate properly or do not satisfy user performance objectives.[11]

Several fundamental reasons or typical examples for poor incinerator performance are outlined in Table 5-2. Typically, if incinerator performance is poor, the incinerator contractor is blamed for providing inferior equipment, but this is not always the cause or the only cause of problems. In fact, incinerator deficiencies or inadequacies usually are related to problems in three areas: selection and/or design (before procurement), fabrication and/or installation (during procurement), and operation and/or maintenance (after acceptance). Examples of deficiencies in these three areas are discussed below.

5.2.1 System Selection and/or Design Deficiencies

When incinerator system and design decisions are made based on incorrect or inadequate waste data or when specific, unique facility requirements are not addressed, problems can ensue. For example, if waste generation rates are underestimated, an incineration system with inadequate capacity will be procured.

Table 5-2. Incineration System Performance Problems

Major Performance Difficulties	Examples
Objectionable stack emissions	Out of compliance with air pollution control regulations. Visible emissions Odors Hydrochloric acid gas deposition and deterioration Entrapment of stack emissions into building air intakes
Inadequate capacity	Cannot accept standard-size waste containers Low hourly charging rates Low daily burning rates (throughput)
Poor burnout	Low waste volume reduction Recognizable waste items in ash residue High ash residue carbon content (combustibles)
Excessive repairs and downtime	Frequent breakdowns and component failures High maintenance and repair costs Low system reliability
Unacceptable working environment	High dusting conditions and fugitive emissions Excessive waste spillage Excessive heat radiation and exposed hot surfaces Blowback of smoke and combustion products from the incinerator
System inefficiencies	Excessive auxiliary fuel usage Low steam recovery rates Excessive operating labor costs.

Source: Reference 6.

Improper waste characterizations also can lead to operating problems. When heating values, moisture content, volatility, density, and physical form are specified improperly, objectionable stack emissions, unacceptable ash quality, or other problems could develop, requiring reductions in incinerator capacity by as much as two-thirds.[6]

System design criteria and associated contract documents also must be checked to ensure that they adequately satisfy the performance objectives. For example, if incinerator furnace volumes are not related to any specific criteria such as acceptable heat-release rates or if waste loaders or ash removal systems are not suitable for the operating schedules or rigors of operation expected, then the system design clearly is inadequate.

5.2.2 Fabrication and/or Installation Deficiencies

The incinerator may be deficient because of inferior workmanship and/or materials used either in the fabrication or installation of the system. The qualifications of the incinerator contractor relate to how serious these deficiencies could be. Unqualified contractors may be unable to or uninterested in providing a system that meets the specified criteria, either because of inexperience or disregard for criteria that differs from their "standard way of doing business or furnishing equipment." Even the most experienced and qualified contractors deviate to some extent from design documents or criteria, because no "standard" or "universal" incineration systems exist, and various substitutions may be proposed. These variations must be evaluated carefully to determine whether they comply with construction criteria and reflect proven design and application. If these variations are not properly assessed, unfortunate consequences could ensue.

The number and severity of fabrication and installation deficiencies also relate directly to quality control during construction. Contractor submittals should be reviewed before equipment is delivered, site inspections should be made during construction to detect possible deficiencies, and specific operating and performance testing should be performed before final acceptance. Some of the common reasons for fabrication and installation deficiencies are:

- An unqualified vendor (manufacturer).
- An unqualified installation contractor.
- Inadequate guidance from the manufacturer to the installation contractor.
- No clear lines of responsibility between the manufacturer and the installation contractor.
- Failure to review manufacturer's drawings, catalog cuts and materials, and construction data to ensure compliance with design documents.
- Inadequate quality control during and after construction.
- Failure to relate payment schedules to system performance milestones.
- Failure to require final acceptance testing.

5.2.3 Operation and/or Maintenance Deficiencies

Successful performance of any incineration system ultimately depends on the abilities, training, and dedication of the operators. Unqualified, uncaring, poorly trained, and unsupervised operators could impair system performance in the shortest time. Incinerators operate under severe conditions and require frequent adjustments and routine preventive maintenance to provide good performance. If regular adjustments and maintenance are not included in planning and budgeting, the incineration system will provide increasingly poor performance and equipment deterioration will be accelerated. Operating incineration equipment until it breaks down results in extensive, costly repair work and substantially reduces equipment reliability. The common operational and maintenance deficiencies that could affect incineration system performance are summarized below.

- Unqualified operators.
- Negligent, irresponsible, or uncaring operators.
- Inadequate operator training programs.
- Failure to maintain recordkeeping or operating logs to monitor and verify performance.
- Inadequate supervision.
- Failure to perform periodic inspections, adjustments, and preventive maintenance.
- Using equipment that requires repairs or maintenance work.

5.2.4 Avoiding Incineration System Deficiencies

To procure a good incineration system, four basic principles should be understood.

- Incineration technology is more of an art than a science—no textbook formulas can guarantee a successful system.
- There is no "universal" incinerator. Incinerators must be selected, designed, and built to meet each facility's specific needs.
- There is no "typical" application. Even similar types of institutions have wide differences in waste types and quantities, waste management practices, space availability, etc.
- Incinerator manufacturers differ widely in capabilities and qualifications.

Based on these principles, six steps for implementing a successful incinerator project are outlined in Table 5-3. If these steps are followed, incinerator deficiencies should be minimized or eliminated, leading to an increased likelihood of a successful incinerator system installation.[6]

5.3 Training, Safety, and Operations

A comprehensive training program for incinerator operators is a key part of any waste management plan for onsite

Table 5-3. Recommended Incineration System Implementation Steps

Step One Evaluations and Selections	Step Two Design (contract) Documents	Step Three Contractor Selection	Step Four Construction and Equipment Installation	Step Five Startup and Final Acceptance	Step Six After Final Acceptance
Collect and consolidate waste, facility, cost, and regulatory data Identify and evaluate options and alternatives Select system and components	Define wastes to be incinerated–avoid generalities and ambiguous terms Specify performance requirements Specify *full* work scope Specify minimum design and construction criteria	Solicit bids from prequalified contractors Evaluate bids on quality and completeness–not strictly least cost Evaluate and negotiate proposed substitutions and deviations Negotiate payment terms Consider performance bonding	Establish lines of responsibility Require shop drawing approvals Provide inspections during construction and installation	Use "punch-out" system for contract compliance Require comprehensive testing: system operation, compliance with performance requirements, and emissions Obtain operator training	Employ qualified and trained operators Maintain operator supervision Monitor and record system operations Provide regular inspections and adjustments Implement preventive maintenance and prompt repairs—consider service contracts

Source: Reference 6.

incineration. Operators must be properly trained to minimize worker exposure to infectious waste, to minimize incinerator emissions, and to promote safe operation of the incinerator. The first step in developing a training program is to work with safety and operating information provided by the manufacturers of the incineration and air pollution control systems. Existing safety procedures in place at the institution also should be reviewed. Regulations and accreditation requirements such as OSHA and JCAHO safety precaution and emergency response plans should be included. The operator training program should include all these types of information. The goal of any incinerator operator training program should be to promote personal safety, safe operation of the incinerator, fire safety, and proper operation and maintenance of the incinerator to minimize emissions and ensure good ash quality.

5.3.1 Personal Safety

Personal safety can be ensured by training all incinerator operators to minimize handling of medical waste and to wear proper personal protective equipment (PPE) during all phases of waste handling and incinerator operation and maintenance procedures. Training should include use of PPE (thick rubber gloves, hard-soled rubber shoes, and safety glasses) as well as procedures to maintain the integrity of medical waste containers.

5.3.2 Equipment Safety Procedures

In addition to procedures recommended by manufacturers, employees must be trained to observe proper cautionary procedures when feeding waste to the incinerator (e.g., containers of flammable liquids or explosives should not be fed into the incinerator), when opening the charging door or cleanout ports, when working around any hot-surface area, and when undertaking any maintenance that involves entering incinerator chambers or other enclosed spaces (e.g., lockout procedures and "buddy" system) to avoid starting up equipment while operators are repairing it. Proper cautionary procedures also should be followed around air pollution control devices to avoid caustic burns from scrubber water treatment systems, and accidents involving dust inhalation, explosions, oxygen deficiency, exposure to heat stress, or exposure to toxic chemicals when maintaining fabric filters.

5.3.3 Fire Safety

Fire safety is particularly important when working around incinerators because of the high temperatures associated with the combustion process. Operators should be trained to exercise caution in three areas: waste storage, waste charging to the incinerator, and ash removal. Waste should be stored away from the incinerator and ash storage areas to prevent access blockage and premature ignition of waste by stray sparks or burning flyash. Waste charging is particularly hazardous, although some equipment is installed with various types of safety equipment to mitigate problems. These problems include burning wastes sticking to charging rams, which then draw the waste out of the incinerator, thereby setting fire to wastes in the charging hopper. Ash handling is another critical area where operators must be trained to avoid fires and burns. Ash may contain hot spots, thus operators should wear all proper PPE and be alert to burning embers during ash handling procedures.

5.3.4 Proper Operation and Maintenance (O&M)

In addition to training operators to operate and maintain all equipment safely, the operators also must be taught proper operation and maintenance of the incineration and air pollution control equipment so as to minimize pollutant emissions from the incinerator. Most of the information needed to teach proper operation and maintenance is obtained from the manufacturers; general training includes how to interpret monitoring and control instrumentation, how to adjust incineration and air pollution control operations, diagnostic procedures to be followed, and proper maintenance schedules to be undertaken.*

Proper incinerator operation depends on maintaining proper operating conditions that are commonly monitored. The parameters that are frequently monitored include temperature, pressure, oxygen, carbon monoxide, opacity, and charge rate. Carbon monoxide levels provide indications of whether complete combustion is occurring. If carbon monoxide levels are excessive, emissions of other, more objectionable pollutants are likely. Measurements of temperature and oxygen often are used by the incineration system automatically to adjust combustion-air inputs and auxiliary fuel rate.

Proper APC system operation depends on several factors that often are monitored as well: pressure and pressure drop, scrubber liquid flow, scrubber liquid pH, and temperature. For venturi scrubbers, pressure drop and scrubber liquid flow usually are controlled automatically. Control of pH is necessary to prevent damage to the scrubber, and temperature control is necessary in fabric filters to prevent damage from condensed acid gases or excessive heat.

Operators should be trained to diagnose various operating problems that contribute to excessive incinerator emissions. For example, excessive stack emissions from controlled-air incinerators may be caused by the following problems:

- Setpoint for the secondary burner temperature is not high enough.
- Excessive negative draft in the primary chamber.
- Excessive infiltration air from the charging door.
- Excessive underfire air from the primary chamber.
- Operating at a primary-chamber temperature that is too high.
- Overcharging.
- Problem wastes.
- Inadequate secondary combustion air.

Operators should know symptoms of poor operation, such as the emission of black or white smoke, to pinpoint the exact adjustments that must be made for proper operation and emission control. For example, black smoke from a controlled-air incineration system indicates incomplete combustion. Adjustments to ensure complete combustion must be made. White smoke may indicate the presence of small aerosols in the effluent gas that can be caused by too much excess air either entraining small particles or cooling the combustion gases prematurely.

Knowledge of maintenance schedules for both incinerator and APC equipment is critical to the proper maintenance and operation of incinerators to avoid emission problems. Incinerators that are operated until they break down generally perform poorly. Air pollution control equipment that is becoming clogged with particulates or suffering from corrosion, erosion, or scaling cannot operate as efficiently as properly cleaned and maintained equipment. Effective preventive maintenance and replacement or repair of damaged equipment will help ensure efficient, clean operation of medical waste incineration systems.

*Since the completion of this seminar, EPA has published an O&M handbook for medical hospital incinerators[8] and has developed a basic operator training course.[29] The American Hospital Association also has developed a 4-day course entitled *Incinerator Operator Training for Medical Waste and Small Volume Waste Combustors*.[35]

Chapter 6
References

When an NTIS number is cited in a reference, that reference is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

1. U.S. EPA. *Medical Waste Management in the United States. First Interim Report to Congress.* EPA/503-SW-90-051A, Office of Solid Waste, Washington, DC, May, 1990.

2. U.S. EPA. *Medical Waste Management in the United States. Second Interim Report to Congress.* EPA/530-SW-90-087A, Office of Solid Waste, Washington, DC, December, 1990.

3. Government Accounting Office (GAO). *Medical Waste Regulation: Health and Environmental Risks Need To Be Fully Assessed.* GAO/RCED-90-86, Washington, DC, March, 1990.

4. U.S. EPA. *Seminar—Medical and Institutional Waste Incineration: Regulations, Management, Technology, Emissions, and Operations.* Center for Environmental Research Information, CERI 89-247, Cincinnati, OH, November, 1989.

5. Doucet, L.G. Infectious Waste Treatment and Disposal Alternatives. Presented at the Symposium on Infection Control: Dilemmas and Practical Solutions, November 3-4, 1988, Philadelphia, PA. Sponsored by the Eastern Pennsylvania Branch of the American Society for Microbiology, June 12, 1989. Paper included in Reference 4.

6. Doucet, L.G. State-of-the-Art Hospital and Institutional Waste Incineration: Selection, Procurement, and Operations. Presented at the 75th Annual Meeting of the Association of Physical Plant Administration of Universities and Colleges, Washington, DC, July 24,1988. Revised, updated, and issued as a Technical Document (No. 055872) through the American Society for Hospital Engineering, January 1986. Paper included in Reference 4.

7. Doucet, L.G. Hospital/Infectious Waste Incineration Dilemma and Resolutions. Presented at First National Symposium on Incineration of Infectious Waste, Washington, DC, May, 1988. Included as paper in Reference 4.

8. U.S. EPA. *Handbook: Operation and Maintenance of Hospital Medical Waste Incinerators.* EPA/625/6-89-024, Office of Air Quality Planning and Standards, Research Triangle Park, NC, and Center for Environmental Research Information, Cincinnati, OH, January, 1990.

9. Corbus, D. Medical Waste Incinerator Emissions and Air Pollution Control. Prepared by Doucet and Mainka for EPA's Center for Environmental Research Information, Cincinnati, Ohio, December, 1990.

10. U.S. EPA. *EPA Guide for Infectious Waste Management.* EPA/500-SW-86-014, NTIS PB86-199130, Office of Solid Waste and Emergency Response, Washington, DC. May, 1986.

11. *Medical Waste Tracking Act of 1988.* Public Law 100-582. EPA/530-SW-89-008, Washington, DC, November 1, 1988.

12. U.S. EPA. *Tracking Medical Wastes.* EPA/530-SW-89-020, Office of Solid Waste, Washington, DC, May, 1989.

13. U.S. EPA. *Background Document, Resource Conservation and Recovery Act, Subtitle J—Demonstration Medical Waste Tracking Program, Section 11003 Tracking of Medical Waste, 40 CFR Part 259, Subparts E-J.* Office of Solid Waste, Washington, DC, 1988.

14. Lee, C. C. *Environmental Engineering Dictionary.* Governmental Institute, Inc., 966 Hungerford Drive, No. 24, Rockville, MD 20850, 1989. As cited in Lee, Huffman, and Nalesnik, *Summary of Current Medical Waste Management Knowledge.* U.S. EPA, Office of Research and Development, Risk Reduction Engineering Laboratory, Cincinnati, OH, January, 1990.

15. U.S. EPA. *Managing and Tracking Medical Wastes—A Guide to the Federal Program for Generators.* EPA/530-SW-89-021, Solid Waste and Emergency Response, Washington, DC, September, 1989.

16. *Code of Federal Regulations.* 40 CFR Parts 260 to 265.

17. *Code of Federal Regulations.* 10 CFR Part 20.

18. *Federal Register,* Vol. 54, No. 102, pp. 22875-23192, May 30, 1989.

19. CDC. *Guideline for Handwashing and Hospital Environmental Control.* NTIS PB85-923404, 1985.

20. CDC. Recommendations for Prevention of Human Immunodeficiency Virus (HIV) Transmission in Health Care Settings. *Morbidity and Mortality Weekly Report,* Vol. 36, August 21, 1987.

21. National Institutes of Health (NIH). Internal Standard Operating Procedures. NIH, Bethesda, MD, 1989.

22. Joint Commission on Accreditation of Health Care Organizations (JCAHO). *JCAHO Accreditation Manual for Hospitals. Volume 1—Standards.* JCAHO, Oakbrook Terrace, IL, 1991.

23. Incinerator Institute of America (IIA). *Incinerator Standards.* IIA, New York, NY, 1968. As cited in Reference 6.

24. Block, S.S. *Disinfection, Sterilization, and Preservation.* Lea and Febiger, Philadelphia, PA, 1977. As cited in Reference 6.

25. Medical SafeTec, Inc. Catalog. Indianapolis, IN, undated. As cited in Reference 6.

26. Cross, F.L., Jr. Comparison of Disposal Techniques for Infectious Waste. Infectious Disposal Conference, Washington, DC. As cited in Lee, Huffman, and Nalesnik, 1990. *Summary of Current Medical Waste Management Knowledge.* U.S. EPA, Office of Research and Development, Risk Reduction Engineering Laboratory, Cincinnati, OH, January, 1990.

27. McRee, R. *Operation and Maintenance of Controlled Air Incinerators.* Joy Energy Systems, Inc., Charlotte, NC, undated. As cited in Reference 4.

28. C. E. Raymond, Inc., Chicago, IL, undated. As cited in Reference 4.

29. U.S. EPA. *Hospital Incineration Operator Training Course Manual.* EPA 450/3-89-004, NTIS PB 89-189880, Research Triangle Park, NC, March, 1989.

30. *Code of Federal Regulations.* 40 CFR Part 61.

31. Maxwell, W.H. Development of New Source Performance Standards for Medical Waste Incinerators. Presented at the Medical Waste Management Workshop. Sponsored by the Air and Waste Management Association, American Industrial Hygiene Association and Midwest Research Institute, September 18-19, 1989, Overland Park, KS. As cited in Lee, C. C., G. L. Huffman, and R.P. Nalesnik, 1990. *Summary of Current Medical Waste Management Knowledge,* U.S. EPA, Office of Research and Development, Risk Reduction Engineering Laboratory, Cincinnati, OH, January, 1990.

32. Anderson 2000, Inc. Catalog. Peachtree City, GA, undated. As cited in Reference 4.

33. Energy and Environmental Research Corporation. *State-of-the-Art-Assessment of Medical Waste Thermal Treatment.* Energy and Environmental Research Corporation, Irvine, CA, December, 1989. As cited in Reference 9.

34. U.S. EPA. *Control Techniques for Particulate Emissions from Stationary Sources, Volume 1.* EPA-450/3-81-0005a, NTIS PB 83-127498, September, 1982. As cited in Reference 4.

35. American Hospital Association (AHA). *Incinerator Operator/Training for Medical Waste and Small Volume Waste Combusters.* Prepared by Calvin R. Brunner and Doucet and Mainka, P.C., for American Hospital Association, American Society for Hospital Engineering, American Society for Healthcare Environmental Services, and Washington State Hospital Association. AHA, Deerfield, IL, October-December, 1991.

☆U.S. GOVERNMENT PRINTING OFFICE: 1993 - 750-002/60160

United States
Environmental Protection Agency
Center for Environmental Research Information
Cincinnati, OH 45268

Official Business
Penalty for Private Use
$300

EPA/625/4-91/030

Please make all necessary changes on the below label, detach or copy, and return to the address in the upper left-hand corner.

If you do not wish to receive these reports CHECK HERE ☐; detach, or copy this cover, and return to the address in the upper left-hand corner.

BULK RATE
POSTAGE & FEES PAID
EPA
PERMIT No. G-35