Non-Incineration Medical Waste Treatment Technologies in Europe

A Recource for Hospital Administrators, Facility Managers, Health Care Professionals, Environmental Advocates, and Community Members

June 2004

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This resource book is based on the report "Non-Incineration Medical Waste Treatment Technologies: A Resource for Hospital Administrators, Facility Managers, Health Care Professionals, Environmental Advocates, and Community Members" issued by Health Care Without Harm in August 2001. While the general chapters on waste minimisation and waste categories are shortened, more space is given to the description of technologies that operate in Europe.

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Preface

Until recently, incineration was the almost exclusive method of treating hazardous medical waste. In 1994, the U.S. Environmental Protection Agency's (EPA) Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds identified medical waste incineration as the single largest source of dioxin air pollution in the United States of America. In 1997, the EPA promulgated regulations for existing and new incinerators, setting new emission limits. Existing incinerators had to be equipped with additional air pollution control devices to comply with the new legislation requirements. For the vast majority of hospitals and other medical waste incinerator operators however, investing in efficient filters was too expensive and resulted in the closure of more than five thousands medical waste incinerators.

In 2000, stricter emission limits for medical waste incinerators were introduced in the European Union. This resulted in the closure of many incinerators and an increase in the number of non-incineration facilities for treating infectious medical waste. However, the speed of the introduction of alternative treatments is much slower than in the USA and incineration remains the prevailing method of treating medical waste in Europe.

Although incineration is still widely used, non-incineration technologies are winning increasing support in Europe. In Slovenia, all infectious waste has been treated by using a steam-based system since 90's. Portugal has closed almost all its medical waste incinerators and is treating medical waste in autoclaves. More than 50 operators in France have introduced shredding/steam/drying systems for medical waste treatment in last 10 years. The Joint Waste Management Board of Ireland decided in 2003 to decontaminate the vast majority of its medical waste by autoclaves using hot steam.

Recently, 10 new countries entered the European Union. Incineration facilities in these countries are mostly old and not complying with EU emission limits for incinerators. In the Czech Republic and Poland, (taking these countries as examples), the overwhelming majority of medical waste incinerators exceed the dioxin emission limit of 0.1 ng/m^3 TEQ.

There are two ways these new member countries can meet the statutory limits in the future – they can either equip incineration plants with very expensive filters, or close them and set up the alternative - non-incineration - technologies. The latter are more environmentally friendly and usually cheaper than incinerators. Non-incineration technologies (unlike incinerators) do not produce toxic dioxins and their introduction is therefore in accordance with the Stockholm Convention on POPs (Persistent Organic Pollutants) that entered into force in May 2004.

It is widely accepted within the scientific community that the incineration of waste results in the formation of Persistent Organic Pollutants, including dioxins, thus contributing to global POPs emissions. Although installation of new air emission control devices could reduce dioxin emissions in stack gas, this is usually accompanied with an increase of dioxin in fly ash. As the Stockholm Convention recognises releases to air, water and land, future support for incineration would go against the primary goal of this convention, which is the reduction of POPs.

The problem of pollution caused by the incineration of medical waste has been recognised by the World Health Organisation (WHO). In its policy paper entitled "Health-care Waste Management" (March 2004) WHO states that a long-term goal shall be: "Effective, scaled-up promotion of non-incineration technologies for the final disposal of health-care wastes to prevent the disease burden from (a) unsafe health-care waste management and (b) exposure to dioxins and furans."

Health Care Without Harm hopes that all countries in Europe will support the development of non-incineration medical waste treatment technologies instead of choosing to reconstruct and equip existing outdated incineration plants or supporting the construction of new ones.

Executive summary

The international Convention on the Elimination of Persistent Organic Pollutants (POPs) lists medical waste incinerators among the main dioxin sources in the environment. However, medical waste incinerators emit a wide range of pollutants besides dioxins and furans. These include heavy metals (lead, mercury and cadmium), fine dust particles, hydrogen chloride, sulphur dioxide, carbon monoxide, nitrogen oxides and other pollutants like Products of Incomplete Combustion (PICs) into the atmosphere. They also generate highly contaminated ash that is potentially hazardous to human health. It is scientifically acknowledged that these pollutants can have serious negative impacts on the health of incineration plant personnel, the public and the environment.

In order to maximise the benefits of non-incineration technologies, a basic concept is presented of which the underlying elements are waste minimisation and segregation. By implementing a program that includes source reduction, segregation, recycling and other pollution prevention techniques, health-care services can reduce the amount of infectious waste that needs to be decontaminated.

A waste analysis is an important step in selecting any non-incineration technology. Contrary to popular belief **infectious medical waste is estimated to be approximately 15% or less of the overall waste stream**. By the introduction of efficient waste segregation and classification systems based on a real threat from infectious waste, this amount can be reduced in many cases to 3-5%.

Medical waste can be defined as waste generated as a result of diagnosis, treatment and immunisation of humans or animals. It is useful to categorise the overall waste stream into the following four categories: **Municipal solid waste, infectious waste, hazardous waste** and **low-level radioactive waste**. Waste categories are specified in the European Waste Catalogue and might be further defined by national legislation. Although infectious waste is only a small part of the total waste generated by medical facilities, it accounts for a considerable portion of the costs incurred by a health care facility for the disposal of medical waste.

Four basic processes are used in alternative medical waste treatment: thermal, chemical, irradiative and biological. Thermal processes rely on heat to destroy pathogens (disease-causing micro-organisms). The low-heat processes utilise moist heat (usually steam) or dry heat. Chemical processes employ disinfectants to destroy pathogens or chemicals to react with the waste. Irradiation involves ionising radiation to destroy micro-organisms while biological processes use enzymes to decompose organic matter. Mechanical processes, such as shredders, mixing arms, or compactors, are added as supplementary processes to render the waste unrecognisable, improve heat or mass transfer, or reduce the volume of treated waste.

For each of these processes, an overview and principles of operation are presented along with information on the types of waste treated, emissions, waste residues, microbial inactivation efficacy, advantages, disadvantages and other issues. Specific examples of technologies in operation in Europe are provided. Technology descriptions are based on vendor data, independent evaluations and other non-proprietary sources where available. Since technologies change quickly in a dynamic market, it is advisable for facilities interested in using a non-incineration method to contact the vendors to get the latest and most accurate data when conducting the evaluation of any technology.

Health Care Without Harm does not endorse any technology, company, or brand name, and does not claim to present a comprehensive list of technologies.

Steam disinfection, a standard process in hospitals, is done in autoclaves and retorts. Tuttnauer is an example of an autoclave. More recent designs have incorporated vacuuming, continuous feeding, shredding, mixing, fragmenting, drying, chemical treatment and/or compaction, to modify the basic autoclave system. Examples of these so-called advanced autoclaves are: Ecodas, Hydroclave, Sterival, STI-CHEM Clav, STS, System Drauschke.

Microwave technology is essentially a steam-based low-heat thermal process where disinfection occurs through the action of moist heat and steam. Ecostéryl, Sanitec, Medister, Sintion, Sterifant, Steriflex are examples of large and small microwave units, respectively. Dry heat processes do not use water or steam. Some heat the waste by forced convection, circulating heated air around the waste or using radiant heaters.

Chemical technologies use disinfecting agents in a process that integrates internal shredding or mixing to ensure sufficient exposure to the chemical. Until recently, chlorine-based technologies (sodium hypochlorite and chloride dioxide) were the most commonly used. Some controversy exists regarding possible long-term environmental effects, especially of hypochlorite and its by-products in wastewater. Non-chlorine technologies are quite varied in the way they operate and the chemical agents employed. Some use peroxyacetic acid (Steris EcoCycle 10), ozone gas (Lynntech), lime-based dry powder, metal catalysts (CerOx), or biodegradable proprietary disinfectants. The alkaline hydrolysis technology (WR^2) is designed for tissue and animal wastes as well as fixatives, cytotoxic agents and other specific chemicals. Safety and occupational exposures should be monitored when using any chemical technology.

Electron beam technology bombards medical waste with ionising radiation, causing damage to the cells of micro-organisms. The University of Miami's Laboratories for Pollution Control Technologies is shown as an examples of e-beam technologies designed for medical waste treatment. Unlike cobalt-60 irradiation, electron beam technology does not have residual radiation after the beam is turned off. However, shields and safety interlocks are necessary to prevent worker exposure to the ionising radiation. Biological processes, such as the Bio-Converter, use enzymes to decompose organic waste.

Health care facilities should consider the following factors when selecting a non-incineration technology:

- Regulatory acceptance
- Throughput capacity
- Types of waste treated
- Microbial inactivation efficacy
- Environmental emissions and waste residues
- Space requirements
- Utility and other installation requirements
- Waste reduction
- Occupational safety and health
- Noise
- Odour
- Automation
- Reliability
- Level of commercialisation
- Background of the technology manufacturer or vendor
- Cost
- Community and staff acceptance.

No one technology offers a panacea to the problem of medical waste disposal. Each technology has its advantages and disadvantages. Facilities have to determine which non-incineration technology best meets their needs while minimising the impact on the environment, enhancing occupational safety and demonstrating a commitment to public health. This resource book provides general information to assist legislators, hospital administrators, facility managers, health care professionals, environmental advocates and community members towards achieving those goals.

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Chapter 1

Introduction: Why non-incineration technologies are preferable to incineration

INCINERATORS EMIT TOXIC AIR POLLUTANTS

Medical waste incinerators emit dioxins, furans and heavy metals including lead, mercury and cadmium, fine dust particles, hydrogen chloride, sulphur dioxide, carbon monoxide, nitrogen oxides, PICs (Products of Incomplete Combustion) and many other pollutants into the atmosphere. These compounds have serious negative impacts on the health of incineration plant personnel, the public and the environment. The International Agency for Research on Cancer (IARC) has classified the most toxic dioxin - 2,3,7,8 TCDD – as a group 1 human carcinogen while some other dioxins are considered possible carcinogenic substances for human beings.[1] Dioxins also affect the hormonal system, impairs organism stamina and are associated with genetic defects, diabetes, endometriosis and a wide range of other diseases.[2,3,4,5]

Additional equipment or the installation of various devices to reduce gaseous emissions will usually increase the content of these pollutants in the solid waste phase. Moreover, the efficiency of filters in capturing very fine particles is limited; a proportion of 5% – 30% is quoted for very fine particles smaller than 2.5 μm, being captured, while those under 1μm are hardly captured at all. These ultrafine particles are highly reactive, even when coming from a relatively inert material. Recent research indicates that inhaling these ultrafine particles may have an adverse effect on human health.[6]

INCINERATION ASH IS POTENTIALLY HAZARDOUS

As a rule, no additional equipment incorporated into an incineration plant with gaseous emission treatment devices will reduce the quantity of dioxins emitted, but, as already stated, will simply transform them into another waste phase. In an incinerator using the Best Available Technology (BAT) the content of dioxins in gaseous emissions was only 2% of the total dioxin content established in all incinerator wastes. The content of dioxins in ash, slag, settlings and filter cake was 6%, 72%, 2% and 18% of the total quantity of released dioxins respectively[7]. In addition to dioxins and furans the ash also contains other dangerous substances and a high content of heavy metals (chrome, copper, lead, nickel, zinc) which can be released into the environment.[8]

Fly ash containing heavy metals, dioxin, furans and other toxic substances fixes to the surface of small particles that are carried by hot air and flue gases up through the incinerator chimney. The efficiency of capturing these substances using flue gas treatment devices depends on the efficiency and quality of the filters used. However, the best filters cannot capture all gaseous emissions. During the flue gas treatment process harmful substances concentrate and are deposited in filter cakes, activated charcoal and in the flue gas treatment process wastewater. This waste is usually classified as dangerous and has to be treated accordingly.

Residual waste from both incineration plants and from non-incineration medical waste treatment technologies[9] has to be disposed of in landfills. In the hierarchy of waste treatment dumping decontaminated waste, which, with its properties, is similar to municipal waste, should be preferred to dumping dangerous waste resulting from incineration. Moreover, the price for dumping hazardous waste from incinerators at the special landfills required for this type of waste is several times higher than that for dumping decontaminated medical waste at landfills for municipal waste, thus increasing the costs to health-care facilities.

INCINERATORS ARE EXPENSIVE

The costs of building and operating an incinerator or a selected non-incineration technology may differ in various countries. This can be because of

different legislation – waste categorisation, different costs for hazardous and municipal wastes, the technology availability and other factors. Generally however, different non-incineration technologies are less expensive than medical waste incinerators. As an illustration, the costs of building an incineration plant in the USA are 3 to 4 times higher than those of processing the same quantity of waste in an autoclave[10]. Also the costs of operating non-incineration technology are usually lower than those of an incineration plant operation.

INCINERATORS MUST MEET NEW EMISSION LIMITS

According to the European Union Directive No. 2000/76/EC on waste incineration, medical waste incinerators must meet the emission limit set at 0.1 ng TEQ/m^3 for dioxins and furans. Currently, the overwhelming majority of medical waste incinerators in new member states and in some west Europe countries, fail to meet this standard. To meet this limit in many cases incineration plants have to be reconstructed or fitted with efficient filters. This can require an investment of thousands, possibly millions of Euros. Investing in less expensive and environmental friendlier non-incineration technologies seems to be a much more profitable alternative.

INTERNATIONAL CONVENTION ON THE ELIMINATION OF PERSISTENT ORGANIC POLLUTANTS (POPS)

The international Convention on the Elimination of Persistent Organic Pollutants (POPs) was signed in Stockholm, Sweden, in May 2001 and entered into force in May 2004. Article 5 requires that countries eliminate the generation of POPs including dioxins originating as by-products of industrial processes. Appendix C lists medical waste incinerators among the main sources of dioxin in the environment.[11]

Most European countries are signatories of the Stockholm Convention and therefore should prepare a plan for reducing persistent organic substances in the environment. Unlike incineration plants, persistent organic pollutants (POPs) are not generated when treating medical waste using non-incineration technologies. Therefore the introduction of non-incineration technologies for the treatment of medical waste is a suitable way of meeting the obligations arising from the Stockholm Convention.

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[1] McGregor, DB., Partensky, C., Wilbourn, J., Rice, JM.: An IARC evaluation of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans as risk factors in human carcinogenesis. Environ. Health Perspect., 1998,106(2):755-60.

[2] Egeland, G., Sweeney, M., Fingerhut, M., Wille, K., Schnoor, T. Total serum testosterone and gonadotropins in workers exposed to dioxin. Am. J. Epidemiol., 1994, 139:272-281.

[3] Birnbaum, L. Developmental Effects of Dioxins. Environ. Health Perspect., 1995, 103(Suppl 7):89-94.

[4] Weisglas-Kuperus, N. Neurodevelopmental, immunological and endocrinological indices of perinatal human exposure to PCBs and dioxins. Chemosphere, 1998, 37:1845-1853.

[5] Sweeney, M., Hornung, R., Wall, D., Fingerhut, M., Halperin, W. Prevalence of diabetes and elevated serum glucose levels in workers exposed to 2,3,7,8-tetrachlordibenzo-p-dioxin (TCDD). Presented at the 12th International symposium on Dioxins and Related compounds, Tampere, Finland, 24-28 August 1992.

[6] Howard C.V., 2000. Particulate Aerosols, Incinerators and Health, in P. Nicolopoulou-Stamati et.al. (eds.), Health Impacts of Waste Management Policies, 155-174, Kluwer Academic Publishers, 2000.

[7] Giugliano, M., Cernuschi, S., Grosso, M., Miglio, R., and Aloigi, E. PCDD/F mass balance in the flue gas cleaning units of a MSW incinerator plant. Chemosphere, 2002, 46:1321-1328.

[8] Čížek Zdeněk. The problematics of the laboratory evaluation of the medical waste qualities. Waste from health care, proceedings, BIJO, 2000.

[9] Decontaminated waste from many hospitals in Europe, i.e. in Austria and in Czech Republic, is subsequently incinerated, whereby the real purpose of implementing non-incineration technologies is to eliminate dangerous persistent organic substances generated by waste incineration.

[10] Emmanuel. J, Non-incineration Alternatives to the Treatment of Medical Waste. Presented at the conference "Environmentally friendly management of medical waste", Debeli rtič, Slovenia, 12th April 2002.

[11] http://www.pops.int

Chapter 2

Waste reduction and segregation – the basic concept for the introduction of non-incineration technologies

Before dealing with the technical and economic issues relating to non-incineration technologies (Chapters 3 to 10), it is crucial to consider the use of these technologies in a broader context. An alternative technology must encompass a strategic framework dealing with various aspects of medical waste management and in doing so ensure that the maximum environmental, occupational safety and economic benefits of non-incineration technologies can be achieved.

In the past, many hospitals simply dumped all their waste streams together — waste from the reception area, kitchen waste, operating room wastes, contaminated sharps and lab waste etc. — and burned them in their incinerators. There were no incentives to separate, recycle, or reduce waste. A commitment to public health and environmental protection, regulatory compliance and the need to reduce costs requires a new framework for dealing with hospital waste.

The underlying elements of a strategic framework are **waste minimisation** and **segregation**. Different components of the waste stream must be kept separate from each other. Specifically, potentially infectious waste, municipal waste, hazardous waste and low-level radioactive waste must be segregated. Every effort must be made to minimise each of these waste streams and each must be disposed of properly. The infectious waste that remains can then be treated using a non-incineration technology. *(Note: Some facilities incinerate waste that had already been treated by a non-incineration technology thereby defeating the purpose of using an alternative.)*

Waste minimisation is the reduction, to the greatest extent possible, of waste that is destined for ultimate disposal by means of reuse, recycling and other programs. The potential benefits of waste minimisation are: environmental protection, enhanced occupational safety and health, cost reductions, reduced liability, regulatory compliance, and improved community relations. The following is the recommended hierarchy of waste minimisation techniques in order of decreasing preference:

1. **Source reduction** - minimising or eliminating the generation of waste at the source itself. Source reduction should have a higher priority than recycling or reuse. Medical staff, waste managers, and product standardisation committees should be aware of what proportions of the waste stream are generated by the products they buy. Indeed, the close involvement of purchasing staff is critical to the effectiveness of any source reduction scheme. Steps should be taken to reduce at source regulated medical waste, hazardous waste, low-level radioactive waste, as well as regular trash. Some specific source reduction techniques include:

    a. **Material elimination, change or product substitution**, e.g., substituting a non-toxic biodegradable cleaner for one that generates hazardous waste; employing multiple-use items instead of single-use products; using short-lived radionuclides instead of radium-226 needles in cancer treatment;

    b. **Technology or process change,** e.g., using non-mercury-containing devices instead of mercury thermometers or mercury switches; using ultrasonic or steam cleaning instead of chemical-based cleaners, replacing chemical based process for development of radiography with a computer one;

    c. **Preferential purchasing** such as selecting vendors with reduced packaging, product recyclability;

    d. **Good operating practice**, e.g., improving inventory control; covering disinfecting solution trays to prevent evaporative losses; using the minimum formulation recommended for an application.

2. **Segregation** – making sure waste items are put in the appropriate containers. Staff training is essential to keep infectious medical wastes and hazardous waste such as mercury, low-level radioactive waste, and municipal waste separated from each other.

3. **Resource recovery and recycling** - recovery and reuse of materials from the waste stream. Some specific examples include:
    a. Recycling newspapers, packaging material, office paper, glass, aluminium cans, construction debris, and other recyclable;
    b. Purchasing products made of post-consumer recycled material;
    c. Composting organic food waste;
    d. Recovering silver from photographic chemicals.

4. **Treatment** - treatment to remove and concentrate waste, preferably during processes rather than end-of-pipe treatment. An example might be the use of filters and traps to remove mercury from wastewater. In the case of infectious waste, the treatment entails the destruction of pathogens. This is where non-incineration technologies come in.

5. **Proper Disposal** – when all possible waste minimisation options have been exhausted, the remaining waste should be disposed in the method with the least environmental impact. With most non-incineration technologies, the treated waste can be disposed in a regular municipal waste landfill.

Health Care Without Harm does not support the incineration, gasification, pyrolysis or plasma destruction of medical waste as means of decontamination or treatment after disinfection.

Chapter 3

Medical waste categories

A waste analysis is an important step in selecting the non-incineration technology that best meets the needs of the facility. Furthermore, a waste stream analysis is a basis for identifying waste minimisation options and establishing the degree of segregation. Through an analysis, the health care facility can establish whether or not some waste is being "over-classified" as bio-hazardous waste, and assess compliance with existing regulations on waste handling and disposal. A waste audit is a powerful tool for analysing the hospital waste stream.

Medical waste can be defined as waste generated as a result of diagnosis, treatment, and immunisation of humans or animals. It is useful to categorise the overall waste stream into the following four categories:

1. **Municipal solid waste** includes recyclable or compostable materials.
2. **Infectious waste** is generally defined as waste that is capable of producing infectious disease. Other terms used include bio-hazardous waste, biomedical waste, or "red bag" waste. Infectious waste must be treated and decontaminated before landfilling (Directive 99/31/EC).
3. **Hazardous waste** is defined as waste that may cause or significantly contribute to mortality or serious illness or pose a substantial hazard to human health and the environment if improperly managed or disposed of.
4. **Low-level radioactive waste** is waste that exhibits radiologic characteristics such as radioactive decay.

Table 3-1. A comparison of medical waste categories according to EU Waste Catalogue and WHO.

European Waste Catalogue	**Categories of health-care waste (WHO)**
18 01 01 sharps (except 18 01 03)	Sharps
18 01 02 body parts and organs including blood bags and blood preserves (except 18 01 03)	Pathological waste
18 01 03* wastes whose collection and disposal is subject to special requirements in order to prevent infection	Infectious waste
18 01 04 wastes whose collection and disposal is not subject to special requirements in order to prevent infection (for example dressings, plaster casts, linen, disposable clothing, diapers)	Non-risk or "general" health-care waste
18 01 06* chemicals consisting of or containing dangerous substances	Chemical waste Waste with high content of heavy metals
18 01 07 chemicals other than those mentioned in 18 01 06	Chemical waste
18 01 08* cytotoxic and cytostatic medicines	Genotoxic waste
18 01 09 medicines other than those mentioned in 18 01 08	Pharmaceutical waste
18 01 10* amalgam waste from dental care	Waste with high content of heavy metals
15 01 11* metallic packaging containing a dangerous solid porous matrix (for example asbestos), including empty pressure containers	Pressurised containers
National regulation [EU proposal: COM(2003) 32 final]	Radiological waste
(*) Indicates waste classified as hazardous	

Waste categories are specified in the European Waste Catalogue, and might be further defined by national legislation. The main focus of this resource guide is the treatment of regulated medical waste.

Infectious waste is estimated to be 15% or less of the overall waste stream. By introduction of efficient waste segregation and classification systems based on a real threat from infectious waste, the amount might be reduced to 3 - 5%.[1] Although infectious waste is only a small part of the total waste generated by medical facilities, it makes up a considerable part of the costs of medical waste disposal. While the proportion of infectious waste in the Hospital Na Homolce (Czech Republic) in 2001 was only 17% of the total hospital waste, the costs of its disposal was 81% of the total costs of disposing of all waste.[2]

[1] Institute of Environmental Medicine and Hospital Epidemiology. Reduction and utilisation of hospital waste, with the focus on Toxic and infectious waste. Final report, LIFE96/ENV/D/10, Freiburg, August 2000.

[2] Based on information provided by the hospital Na Homolce, Czech Republic.

Chapter 4

Non-incineration technologies – general categories and processes

Non-incineration treatment technologies can be classified in many ways - such as according to size, purchase price, types of waste handled, or market share. In this chapter, the technologies will be categorised based on the fundamental processes used to decontaminate waste. The four basic processes are:

1. **Low-heat thermal processes**
2. **Chemical processes**
3. **Irradiative processes**
4. **Biological processes**

The majority of non-incineration technologies employ the first two processes listed above. Presented below are each of these processes as well as **mechanical processes** which supplement the four fundamental processes.

Thermal processes are those that rely on heat (thermal energy) to destroy pathogens in the waste. This category is further subdivided into low-heat, medium-heat, and high-heat thermal processes. This further sub-classification is necessary because physical and chemical mechanisms that take place in thermal processes change markedly at medium and high temperatures.

Low-heat thermal processes are those that use thermal energy to decontaminate the waste at temperatures insufficient to cause chemical breakdown or to support pyrolysis or combustion. Medical waste incinerators, pyrolysis, gasification, and plasma arc technologies are considered to be high-heat processes, involving chemical and physical changes to both organic and inorganic material resulting in destruction of the waste.

Medical waste incinerators are a major source of persistent organic pollutants, including dioxins. Due to the negative impact on human health, incineration of medical waste should not be recommended and the preferred treatment for medical waste.

LOW-HEAT THERMAL PROCESSES

In general, low-heat thermal technologies operate between 93°C to about 177°C. Two basic categories of low-heat thermal processes are wet heat (steam) and dry heat (hot air) disinfection. Wet heat treatment involves the use of steam to disinfect and sterilise waste and is commonly done in an autoclave. Microwave treatment is essentially a steam disinfection process since water is added to the waste and destruction of micro-organisms occurs through the action of moist heat and steam generated by microwave energy[1]. In dry heat processes, no water or steam is added. Instead, the waste is heated by conduction, natural or forced convection, and/or thermal radiation using infrared heaters.

CHEMICAL PROCESSES

Chemical processes employ disinfectants such as dissolved chlorine dioxide, bleach (sodium hypochlorite), peracetic acid, or dry inorganic chemicals. To enhance exposure of the waste to the chemical agent, chemical processes often involve shredding, grinding, or mixing. In liquid systems, the waste may go through a dewatering section to remove and recycle the disinfectant. Besides chemical disinfectants, there are also encapsulating compounds that can solidify sharps, blood, or other body fluids within a solid matrix prior to disposal. One developing technology uses ozone to treat medical waste and others utilise catalytic oxidation. A novel system uses alkali to hydrolyse tissues in heated stainless steel tanks.

IRRADIATIVE PROCESSES

Irradiation-based technologies involve electron beams, Cobalt-60, or UV irradiation. These technologies require shielding to prevent occupational exposures. Electron beam irradiation uses a shower of high-energy electrons to destroy micro-organisms in the waste by causing chemical dissociation and rupture of cell walls. The pathogen destruction efficacy depends on the dose absorbed by the

mass of waste, which in turn is related to waste density and electron energy. Germicidal ultraviolet radiation (UV-C) has been used as a supplement to other treatment technologies. Irradiation does not alter the waste physically and would require a grinder or shredder to render the waste unrecognisable.

BIOLOGICAL PROCESSES

Biological processes employ enzymes to destroy organic matter. Only a few non-incineration technologies have been based on biological processes.

MECHANICAL PROCESSES

Mechanical processes - such as shredding, grinding, hammermill processing, mixing, agitation, liquid-solid separation, conveying (using augers[2], rams, or conveyor belts), and compaction – supplement other treatment processes. Mechanical destruction can render the waste unrecognisable and is used to destroy needles and syringes so as to minimise injuries or to render them unusable. In the case of thermal- or chemical-based processes, mechanical devices such as shredders and mixers can also improve the rate of heat transfer or expose more surfaces to chemical disinfectants. Mechanical processes can add significantly to the level of maintenance required.

A mechanical process is supplementary and cannot be considered a treatment process *per se. Unless shredders, hammermills, and other mechanical destruction processes are an integral part of a closed treatment system, they should not be used before the waste is decontaminated.* Otherwise, workers would be exposed to pathogens released to the environment by mechanical destruction. If mechanical processes are part of a system, the technology should be designed in such a way that the air in and from the mechanical process is disinfected before being released to the surroundings. It is especially important for air to be drawn into the mechanical process (away from the inlet) when waste is being fed. This is often done using a draft fan that maintains a negative pressure in the mechanical processing chamber; air taken from the mechanical process passes through the disinfection chamber or through a high efficiency particulate air (HEPA) filter before being released to the environment.

Table 4-1 lists some non-incineration technologies according to category. These technologies range from small units for use at or near the point of generation to high-capacity systems for large medical centres or regional facilities.

These technologies are described in subsequent chapters.

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[1] Various studies show that the lethal effect of microwaves on microbial organisms is primarily due to moist heat; without water or steam, microwave energy alone results in no significant cell inactivation. See, for example, G.R. Vela and J.F. Wu. Applied and Environmental Microbiology, 1979, 37(3), 552.

[2] An auger is essentially a large screw that rotates inside a cylinder thereby moving the waste forward.

Table 4-1. Non-incineration treatment technologies for medical waste

Non-incineration Technology	*Technology name, vendor*
LOW-HEAT THERMAL PROCESSES	
Autoclave or Retort	Tuttnauer
Shredding-Steam-Mixing/Drying	Ecodas
Steam-Mixing-Fragmenting/Drying	Hydroclave Systems Corp.
Shredding-Steam-Mixing/Drying, Chemical	Steriflash, T.E.M.
Vacuum-Steam/Drying/Shredding	Sterival, Starifant Vetriebs GmbH
Shredding-Steam/Drying, Chemical	STI Chem-Clav, Waste Reduction Europe Ltd
Shredding-Steam-Mixing/Compaction	STS, Erdwich Zerkleinerungssysteme GmbH

Non-incineration technology	*Technology name, vendor*
Vacuum-Steam/Drying/Shredding	System Drauschke, GÖK Consulting AG
Steam-Fragmenting/Drying	ZDA-M3, Maschinenvertrieb für Umwelttechnik GmbH
Microwave Treatment	Ecostéryl, AMB S.A.
Microwave Treatment	Medister, Meteka
Microwave Treatment	Sanitec
Microwave Treatment	Sintion, CMB Maschinenbau und Handels GmbH
Vacuum-Steam/Microwave Treatment/Drying/Shredding	Sterifant Vertriebs GmbH
CHEMICAL PROCESSES	
Fragmenting-Steam-NaClO/Cl_2O	Newster, Multiservice First s.r.l.
Alkaline Hydrolysis	WR^2, Waste Reduction Europe Ltd
IRRADIATION PROCESSES	
Electron Beam-Shredding	U. Miami E-Beam
BIOLOGICAL PROCESSES	
-	Today not available in Europe

Health Care Without Harm does not endorse any technology, company, or brand name. These technologies are listed here as examples of alternatives to traditional incineration. HCWH does not claim that this is a comprehensive listing.

Chapter 5

Low-heat thermal technologies: autoclaves, microwaves and other steam based systems

SYSTEMS BASED ON HOT STEAM APPLICATION – AUTOCLAVES, RETORTS

Steam disinfection, a standard process in hospitals for sterilising reusable instruments, has been adapted for medical waste treatment. There are two traditional types of equipment used for steam treatment: autoclaves and retorts. Other steam-based systems, sometimes referred to as advanced autoclaves, have been developed in recent years. One unique design of a steam-based process is a microwave unit that achieves disinfection or sterilisation by means of moist heat and steam.

An **autoclave** consists of a metal chamber sealed by a charging door and surrounded by a steam jacket. Steam is introduced into both the outside jacket and the inside chamber which is designed to withstand elevated pressures. Heating the outside jacket reduces condensation in the inside chamber wall and allows the use of steam at lower temperatures. Because air is an effective insulator, the removal of air from the chamber is essential to ensure penetration of heat into the waste. This is done in two general ways: gravity displacement or pre-vacuuming.

A *gravity-displacement (or downward-displacement) autoclave* takes advantage of the fact that steam is lighter than air; steam is introduced under pressure into the chamber forcing the air downward into an outlet port or drain line in the lower part of the chamber. A more effective method is the use of a vacuum pump to evacuate air before introducing steam, as is done in pre-vacuum autoclaves.

Pre-vacuum (or high-vacuum) autoclaves need less time for disinfection due to their greater efficiency in taking out air. Some autoclaves may use pressure pulsing with or without gravity displacement to evacuate air.

A **retort** is similar to an autoclave except that it has no steam jacket. It is cheaper to construct but requires a higher steam temperature than an autoclave. Retort-type designs are found in large-scale applications.

HOW IT WORKS

A typical operating cycle for an autoclave or retort involves the following:

- *Waste collection*: A cart or bin is lined with special plastic liners or large autoclavable bags to prevent waste from sticking to the container. Red bags are then placed in the lined container.
- *Pre-heating* (for autoclaves): Steam is introduced into the outside jacket of the autoclave.
- *Waste loading*: Waste containers are loaded into the autoclave or retort chamber. Periodically, chemical or biological indicators are placed in the middle of the waste load to monitor disinfection. The charging door is closed, sealing the chamber.
- *Air evacuation*: Air is removed through gravity displacement or pre-vacuuming as explained above.
- *Steam treatment*: Steam is introduced into the chamber until the required temperature is reached. Additional steam is automatically fed into the chamber to maintain the temperature for a set time period.
- *Steam discharge*: Steam is vented from the chamber, usually through a condenser, to reduce the pressure and temperature. In some systems, a post-vacuum cycle is used to remove residual steam.
- *Unloading*: Usually, additional time is provided to allow the waste to cool down further, after which the treated waste is removed and the indicator strips, if any, are removed and evaluated.
- *Mechanical treatment*: Generally, the treated waste is fed into a shredder or compactor prior to disposal in a sanitary landfill.

TYPES OF WASTE TREATED

The types of waste commonly treated in autoclaves and retorts are: cultures and stocks, sharps, materials contaminated with blood and limited amounts of fluids, isolation and surgery wastes, laboratory wastes (excluding chemical waste), and soft wastes (gauze, bandages, drapes, gowns, bedding, etc.) from patient care. With sufficient time and temperature as well as mechanical systems to make the waste unrecognisable it is technically possible to treat human anatomical wastes but ethical, legal, cultural, and other considerations preclude their treatment.

Volatile and semi-volatile organic compounds, chemotherapeutic wastes, mercury, other hazardous chemical wastes, and radiological wastes should *not* be treated in an autoclave or retort. Huge and bulky bedding material, large animal carcasses, sealed heat-resistant containers, and other waste loads that impede the transfer of heat should also be avoided.

EMISSIONS AND WASTE RESIDUES

Odours can be a problem around autoclaves and retorts if there is insufficient ventilation.

If waste streams are not properly segregated to prevent hazardous chemicals from being fed into the treatment chamber, toxic contaminants will be released into the air, condensate, or in the treated waste. This is the case when waste loads contaminated with antineoplastic drugs or heavy metals such as mercury are put in the autoclave. Thus, poorly segregated waste may emit low levels of alcohol, phenols, aldehydes, and other organic compounds in the air. More independent emission tests of autoclaves operating under typical conditions would be useful.

A study[1] at one autoclave facility by the US National Institute for Occupational Safety and Health (NIOSH) found no volatile organic compounds (VOCs) in a worker's personal air space and work area that exceeded permissible exposure limits set by the US Occupational Safety and Health Administration. The highest VOC level in the autoclave facility was 2-propanol, measured at 643 mg/m^3. Some autoclaves or retorts may use steam that is treated with corrosion inhibitors or anti-scaling agents (small amounts of neutralising amines).

There have been dubious claims that dioxin may be created in autoclaves and at levels even higher than those from incinerators. The authors are not aware of any scientific paper showing this. Researchers generally agree that dioxins are formed at temperatures between 250 to 450°C, temperatures well above the operating temperatures of autoclaves. Moreover, dioxin formation is believed to be catalysed by fly ash created during combustion in the presence of metals and a chlorine source. Both the above mentioned temperature range and fly ash are not found in autoclaves since burning does not take place in an autoclave. However, these conditions, along with known precursors (compounds produced by burning that lead to the formation of dioxin) are found in the exhaust downstream from the combustion chambers of incinerators.

Decontaminated waste from an autoclave or retort retains its physical appearance. Some landfill operators may refuse to accept treated waste that is recognisable. Since steam does not physically alter the waste in any significant way, a mechanical process such as a shredder or grinder is needed to render the waste unrecognisable. Shredding reduces the volume of the treated waste by 60 to 80 percent.

MICROBIAL INACTIVATION

Autoclaves and retorts require a minimum exposure time and temperature to achieve proper disinfection or sterilisation. Time-temperature recommendations for various conditions are found in a number of references[2]. Often, the exposure times are based on twice the minimum time required to achieve a 6 $\log_{10}$ kill of bacterial spores under ideal conditions; equivalent exposure times at different temperatures can be estimated. A common exposure temperature-time criterion is 121°C for 30 minutes.

Colour-changing chemical indicators or biological monitors (e.g., B. *stearothermophilus* or B. *subtilis* spore strips) placed at the centre of test loads should be used to verify that sufficient steam penetration and exposure time have occurred.

ADVANTAGES AND DISADVANTAGES OF THE TECHNOLOGY

Autoclaves and retorts have the following advantages:

- Steam treatment is a proven technology with a long and successful track record.
- The technology is easily understood and readily accepted by hospital staff and communities.
- It is approved or accepted as a medical waste treatment technology in most countries.
- The time-temperature parameters needed to achieve high levels of disinfection are well established.
- Autoclaves are available in a wide range of sizes, capable of treating from a few kilograms to several tons per hour.
- If proper precautions are taken to exclude hazardous materials, the emissions from autoclaves and retorts are minimal.
- Capital costs are relatively low .
- Many autoclave manufacturers offer features and options such as programmable computer control, tracks and lifts for carts, permanent recording of treatment parameters, autoclavable carts and cart washers, and shredders.

The disadvantages include the following:

- The technology does not render waste unrecognisable and does not reduce the volume of treated waste unless a shredder or grinder is added.
- Any large, hard metal object in the waste can damage any shredder or grinder.
- Offensive odours can be generated but are minimised by proper air handling equipment.
- If hazardous chemicals such as formaldehyde, phenol, cytotoxic agents, or mercury are in the waste, these toxic contaminants are released into the air, wastewater, or remain in the waste to contaminate the landfill.
- If the technology does not include a way of drying the waste, the resulting treated waste will be heavier that when it was first put in because of condensed steam.
- Barriers to direct steam exposure or heat transfer (such as inefficient air evacuation; excessive waste mass; bulky waste materials with low thermal conductivity; or waste loads with multiple bags, air pockets, sealed heat-resistant containers, etc.) may compromise the effectiveness of the system to decontaminate waste. Examples of waste that may need to be collected separately and treated using another technology include evacuated containers and pleurovac machines.

EXAMPLES OF SYSTEMS BASED ON STEAM APPLICATION

Some examples of hot steam based systems are in Table 4-1. The following are descriptions of all vendors known to the authors as of the time of this publication. While there may be other manufacturers in the market, there was no attempt to make this a comprehensive list. As noted earlier, mention of a specific technology in this report should not be construed as an endorsement by Health Care Without Harm

Tuttnauer

Red bags are placed in an autoclavable bag and manually placed into autoclave baskets resting on a carriage. The full basket is rolled off the carriage into the autoclave chamber. The operator closes the door and pushes a button to automatically start a pre-programmed cycle. Air is removed using a vacuum and heated to 148°C in a heat exchanger prior to discharge in the sewer. Steam is introduced and the waste is exposed for a set period. The vessel can operate up to 155°C and 2.27 bar. After treatment, a high vacuum is pulled to cool and dry the waste. The basket is then rolled out of the chamber and onto the carriage, where it can be transported to a shredder or compactor. The units are equipped with microcomputer-based controls.

Capacity: Up to 680 kg/h.

Capital Costs: 85–170 000 EUR.

Technical information: Temperature: 148 - 155°C; pressure: 2.27 bar; time of exposure: 20 minutes.

Stage of commercialisation: Commercialised.

Vendor's contact: Tuttnauer Co. Ltd., 25 Power Drive Hauppauge, NY,11788, USA, tel.: +1 631 737 4850, e-mail: info@tuttnauer.com, www.tuttnauer.com; Tuttnauer Europe b.v., Paardeweide 36, P.O.B. 7191, 4800 GD Breda, The Netherlands, tel: +31 765 423 510, e-mail: info@tuttnauer.nl

Ecodas

Medical waste is loaded from the top of the machine into a chamber equipped at the bottom with heavy-duty shredder. If waste contains some large unbreakable objects, like metal parts, the shredder stops automatically, and the chamber is not opened until waste is sterilised by steam. Shredded waste falls by gravity into the lower chamber. The machine is steam heated to a temperature of 138°C and pressure is increased to 3.8 bar.

The fully automatic and online controlled process has a cycle time of 40 - 60 minutes, depending upon the size of plant and the amount of waste. Sterile fragments (8 $\log_{10}$ reduction) are discharged from the bottom of the machine and disposed of in a conventional landfill site. The original volume of waste is reduced by 80%.

There are three different models of Ecodas. The major difference between T1000 and T300 is the height and between T2000 and T1000 the diameter. Therefore T2000 and T1000 require a hoist loading system. The cost of waste treatment process ranges from 0.05 to 0.09 EUR/kg. Approximate investment costs are from 145 000 to 400 000 EUR[3].

Ecodas autoclaves are installed in several places in France, mostly in individual medical facilities, but are operated also as central units for other hospitals, for example in Santes or Loos. These systems are also operated in Cyprus, Hungary, Poland, Russia, Spain, and some non-European countries such as Argentina, Brazil, Mexico, Japan, Egypt, Lebanon, Guyana and Morocco.

Capacity: 25 (0.3 m^3)/80 (1 m^3)/190 kg/h (2 m^3).

Capital costs: from 145 000 EUR.

Technical information: Temperature: 138°C; pressure: 3.8 bar; exposure time: 10 minutes.

Stage of commercialisation: Commercialised, since 1993.

Vendor's contact: Ecodas, 28, rue Sebastopol, 59100 Roubaix, France; tel.: +33 3 20 70 98 65, fax: +33 3 20 36 28 05, e-mail: contact@ecodas.com, www.ecodas.com

Hydroclave

The Hydroclave is basically a double-walled (jacketed) cylindrical vessel with mixing and fragmenting paddles inside. The waste is loaded through the loading door on top of the vessel. After the door is closed, high temperature steam enters the outside jacket to heat up the waste via the hot inner surface. During this time, a shaft and paddles rotate inside to fragment and tumble the waste. The moisture in the waste turns to steam and pressurises the inner vessel; however, if there is not enough moisture, a small amount of steam is added until the desired pressure is met. The temperature is maintained at 132°C for 15 minutes (or 121°C for 30 minutes) while the mixing paddles continue to rotate. After treatment, the steam is vented through a condenser while maintaining heat input, causing the waste to dry. The steam to the jacket is shut off, the discharge door is opened, and the shaft and paddles reverse rotation to scoop the waste out through the loading door onto a conveyor or waste container. A strip chart recorder documents the process parameters.

Capacity: 90 - 900 kg/h.

Capital costs: 170 000 - 420 000 EUR.

Technical information: Temperature: 132°C; time of exposure: 15 minutes.

Stage of commercialisation: Commercialised, since 1994.

Vendor's contact: Hydroclave System Corporation, 672 Norris Court, Kingston, ON. Canada K7P 2R9, tel.: +1 613 389-8373, fax: +1 613 389-8554, e-mail: inquire@hydroclave.com, www.hydroclave.com

Steriflash

Steriflash is an autoclave intended for a small waste quantity. It can be installed near the place of waste origin.

Waste deposited in the hopper is mechanically shredded and then falls into the treatment tank. The process begins by the injection of saturating wet steam supplied by an external steam generator (outside the process chamber). The temperature achieved is 134°C at 2.3 bar pressure for 20 minutes.

At the end of the cycle, the front door opens automatically and the solid spun waste is released into a container - liquids are drained off via the waste water system.

Gaseous discharges are filtered (0.3µ filter), condensed and treated by bubbling.

Steriflash installations operate in France, Greece, and Spain. Company is also present on German, Norwegian, Polish, and Swedish market.

Capacity: *Approx.* 16 kg/cycle (0.38 m^3).

Capital costs: 30 000 EUR.

Technical information: Temperature: 134°C; pressure: 2.3 bar; time of exposure: 20 minutes.

Stage of commercialisation: Commercialised.

Vendor's contact: T.E.M.; Hôtel d'entreprises ZI la Pradelle voie la pradelle, 31190 Auterive, France; tel.: + 33 5 342 80 234, fax: + 33 5 342 80 237, e-mail: tem31@wanadoo.fr, www.steriflash.fr

Sterival

The Sterival system is designed for on-site sterilisation of infectious waste. The system is modular and its configuration can be adapted at any time to the capacity required.

The Sterival system consists of an energy (base) and steam supply module. The base module may control up to 4 sterilisation modules and by adding extensions units of 2 up to 4 modules can be assembled. The system uses 60 litres reusable Sterifant PC-waste bins. These can be used in average 200-300 times, depending on the bin model.

The duration of the complete sterilisation cycle at 136°C ranges from 25 to 35 minutes, depending on the waste content, and assuming 12 kg of waste per bin.

The systems require no chemicals, as wastes are sterilised solely by a pulsed vacuum and saturated steam.

Combining the modules with the Sterifant stand-alone shredder can reduce the volume of the post-process waste up to 80%.

The waste treatment process is specified in the list of approved disinfecting processes under § 10 c of the German Epidemics Control Act compiled by the Federal German Health Agency under the name of Valides® System. Sterival modular sterilisation system of medical waste is installed (as the Valides® System) in the new constructed London Hospital in Kuwait, moreover in the major hospital in Munich, Germany.

Capacity: Approx. 21 – 84 kg/h.

Capital costs: 98 100 – 200 400 EUR.

Technical information: Temperature: 136°C; pressure: 2.1 bar; time of exposure: 30 minutes.

Stage of commercialisation: Commercialised.

Vendor's contact: Sterifant Vertriebs GmbH; 12, Rue Jean Engling, L-1466 Luxembourg; tel.: +352-43 22 22-1, fax: +352-42 60 59, sterilux@pt.lu, www.sterifant.com

STI Chem-Clav

With the STI Chem-Clav, the waste is loaded via feed conveyors or cart dumpers into the hopper where a negative pressure is maintained by drawing air through a high efficiency particulate air filter (HEPA). The waste in the hopper drops into a heavy-duty shredding unit where downward pressure is applied using a ram. An integral process controller controls the feed mechanism. Shredded material enters a rotating auger conveyor where low-pressure steam is introduced through multiple ports maintaining the temperature in the conveyor between 114 to 128°C. Downstream of the conveyor is a dehydration section wherein a steam jacket increases temperatures above 118°C. The steam is discharged through a vent at the very end of

the conveyor and through a condenser causing the waste to dry off. The decontaminated waste exits the conveyor into a self-contained compactor or roll-off container for transport to a landfill. A chemical subsystem injects sodium hypochlorite mist for cleaning and odour control. The heavy-duty shredder reduces waste volume up to 90%.

Capacity: 270 – 1800 kg/h.

Capital costs: From 305 000 EUR.

Technical information: Temperature: 118 - 128°C.

Stage of commercialisation: Commercialised since 1995.

Vendor's contact: Waste Reduction by Waste Reduction Europe Ltd., Clydebank Riverside Medi-Park, Beardmore Street, Clydebank, Glasgow G81 4SA, UK; tel.: +44 0 141 951 5980, fax: +44 0 141 951 5985; e-mail: wreurope@wreurope.com, www.wreurope.net; www.stichemclav.com

STS

Medical waste is fed into a funnel through a hydraulic lift mechanism, and shredded after the funnel lid is closed. The shredded "cold" waste is enriched with certain basic moisture content by adding vapour in the lower part of the screw. During the transport process, the water evaporates due to contact with the heated screw walls and evaporation heat is transferred to the "cold" material during the subsequent condensation process. Due to condensation and convection the temperature of the waste is steadily increased.

The heated waste is then transported to the thermal screw, which is also equipped with a thermal oil jacket heating system. During this stage, the temperature range is between 124 – 134°C, and 140°C, but in special cases it can be increased up to 150°C. The material is kept continually in motion during sterilisation process.

As a result of the motion and the loose bulk density of the waste in the thermal screw, the waste is compressed on its way to the discharger. Disinfected and sterilised waste is pourable and its volume reduced considerably.

This technology can be used not just for processing of hospital specific waste, but also for catering waste, slaughterhouse waste, liquids, animal testing laboratories etc.

Capacity: 250 - 300 kg/h.

Capital costs: 550 000 EUR.

Technical information: Temperature: 124 - 150°C; pressure: 2.4 bar; exposure time: 20 minutes.

Stage of commercialisation: Commercialised since 2001.

Vendor's contact: Erdwich Zerkleinerungssysteme GmbH, Kolpingstrasse 8, D-86916 Kaufering, Germany; tel.: +49 08 191 96 52-0, fax: +49 08 191 96 52-16, infoline@erdwich.de, www.erdwich.de

System Drauschke

The waste treatment plant consists of a stationary autoclave and a supply unit. On request, the company supplies it as a mobile unit. The autoclave is a double-walled pressure vessel with capacity of about 13 m^3. It can be sealed in a pressure and vacuum tight way by means of a special closure. For loading and unloading purposes, the cylindrical container can be tilted in a horizontal direction.

Infectious waste is placed in special paper bags with a plastic lining. Liquid wastes are placed in polystyrene drums. The bags and drums are placed in lockable container, and put into autoclave chamber. The autoclave process disinfects the infectious waste by applying a total temperature of 121°C and a pressure of 2.1 bar. To avoid the so-called "cold air islands" in the waste, a fractionated vacuum process is applied in which the disinfection chamber is evacuated several times, and subsequently the steam is injected. The disinfection process is fully automatic. After treatment the waste is disposed of in a landfill.

On a client order the company delivers a shredder and compactor.

System Drauschke is approved disinfecting processes under §10c of the German Epidemics Control Act. Further, it fulfils the requirements of the European Norm EN 285 for large sterilisators.

The Drauschke System was operating in Germany at various sites (Hamburg, Berlin, Thüringen) in the 1990s. There are no plants working in Germany today but since 2003 there is one 'System Drauschke' operating in Slovenia.

Capacity: 140 – 1450 kg/h.

Capital costs: 500-600 000 EUR.

Technical information: Temperature: 121°C; pressure: 2.1 bar; time of exposure: 30 minutes.

Stage of commercialisation: Commercialised; during reorganisation.

Vendor's contact: GÖK Consulting AG
Am Schlangengraben 20, 13597 Berlin, Germany
tel.: +49 30 351 99 680, fax: +49 30 351 99 640, info@goek-consulting.de, www.goek-consulting.de

ZDA-M3

Contaminated medical waste is put into the plant, crushed by a cutter, and disinfected with hot steam. The disinfecting temperature is required to be 105°C, but it is possible to set a higher temperature up to 140°C. The disinfecting period lasts 15 minutes. The plant is controlled by computer; the temperature, pressure and disinfection (sterilisation) period can be set to individual requirements.

The mobile ZDA-M3 plant, type II, manufactured by Maschinenvertrieb für Umwelttechnik GmbH and approved and certified in the Germany (according to BGA-Liste, Section 10c BSeuchG), is used to disinfect medical waste in Slovenia. ZDA-M3 is also certified for use in Switzerland, Spain and New York, USA, and approval has been applied for in France, Italy and Benelux[4]. The autoclave also operates in Rybnik, Poland, where it serves the needs of the town's hospital and medical practices.

Capacity: Approx. 90 kg/h (1.1 m^3).

Capital costs: Not specified.

Technical information: Temperature: 105°C (higher temperature possible); pressure: 5 bar; exposure time: 15 minutes.

Stage of commercialisation: Commercialised, since 1995.

Vendor's contact: User in Slovenia: Mollier, Opekarniška 3, 3000 Celje, Slovenia; tel.: +386 3 42 88 400, fax: +386 3 42 88 402, info@mollier.si, www.mollier.si

MICROWAVE SYSTEMS

Microwave disinfection is essentially a steam-based process in which disinfection occurs through the action of moist heat and steam generated by microwave energy.

Microwaves are very short waves in the electromagnetic spectrum. They fall in the range of the radio frequency band, above ultra-high frequency (UHF) used for television and below the infrared range. A *magnetron* is used to convert high voltage electrical energy into microwave energy, which is then transmitted into a metal channel called a *waveguide* that directs the energy into a specific area (such as the cooking area of a microwave oven or the treatment section of a disinfection unit).

In general, microwave systems consist of a disinfection area or chamber into which microwave energy is directed from a microwave generator (magnetron). Typically, 2 to 6 magnetrons are used with an output of about 1.2 kW each. Some systems are designed as batch processes and others are semi-continuous. The microwave treatment systems that have successfully established itself in the alternative technology market in Europe are Medister, Sanitec, Sintion, Sterifant.

HOW IT WORKS

The operation of a microwave unit (based on a Sanitec Microwave system) is as follows:

- *Waste loading*: Red bags are loaded into carts that are attached to the feed assembly. High temperature steam is then injected into the feed hopper. While air is extracted through a HEPA filter, the top flap of the hopper is opened and the container with waste is lifted and tipped into the hopper.

- *Internal shredding*: After the hopper flap is closed, the waste is first broken down in the hopper by a rotating feed arm and then ground into smaller pieces by a shredder.

- *Microwave treatment*: The shredded particles are conveyed through a rotating conveyor screw where they are exposed to steam then heated to between 95°C and 100°C by four or six microwave generators.

- *Holding time*: A holding section ensures that the waste is treated for a minimum total of 30 minutes.

- *Optional secondary shredder*: The treated waste may be passed through a second shredder breaking it into even smaller pieces. This is used when sharps waste is treated. The optional secondary shredder can be attached in about 20 minutes prior to operation. It is located at the end of a second conveyor screw.

- *Discharge*: The treated waste is conveyed using a second conveyor screw or auger, taking waste from the holding section and discharging it directly into a bin or roll-off container. The bin can be sent to a compactor or taken directly to a sanitary landfill.

TYPES OF WASTE TREATED

The types of waste commonly treated in microwave systems are identical to those treated in autoclaves and retorts: cultures and stocks, sharps, materials contaminated with blood and body fluids, isolation and surgery wastes, laboratory wastes (excluding chemical waste), and soft wastes (gauze, bandages, drapes, gowns, bedding, etc.) from patient care. With sufficient time and temperature, as well as the mechanical systems to achieve unrecognisability, it is technically possible to treat human anatomical wastes but ethical, legal, cultural, and other considerations preclude their treatment.

Volatile and semi-volatile organic compounds, chemotherapeutic wastes, mercury, other hazardous chemical wastes, and radiological wastes should *not* be treated in a microwave.

EMISSIONS AND WASTE RESIDUES

Studies[5] by a laboratory group in Connecticut, a research lab in London, and a research institute in Lyon (France) indicated that aerosol emissions are minimised by the design of the Sanitec unit.

If waste streams are not properly segregated to prevent hazardous chemicals from being fed into the treatment chamber, toxic contaminants will be released into the air, condensate, or in the treated waste. An independent study[6] by the National Institute for Occupational Safety and Health (NIOSH) found no volatile organic compounds (VOCs) in a worker's personal air space and work area at a microwave facility that exceeded permissible exposure limits set by the Occupational Safety and Health Administration. The highest VOC level in the autoclave facility was 2-propanol, measured at 2318 mg/m^3.

MICROBIAL INACTIVATION

A microbiological study[7] on treated waste from a microwave unit showed no growth of micro-organisms (corresponding to a 7 $\log_{10}$ kill or better) for the following test organisms: *Bacillus subtilis, Pseudomonas aeruginosa, Staphlococcus aureus, Enterococcus faecalis, Nocardia asteroides, Candida albicans, Aspergillus fumigatus, Mycobacterium bovis, Mycobacterium fortuitum*, and duck hepatitis. No growth was also shown (greater than 3 $\log_{10}$ kill) for *Giardia miura*. Other studies[8] show the efficacy of microwave disinfection for other micro-organisms under moist conditions.

ADVANTAGES AND DISADVANTAGES OF THE TECHNOLOGY

Microwave technology has the following advantages:

- Because many people have microwave ovens, it is easy for hospital staff and communities to understand and accept the technology.

- It is accepted or approved as an alternative technology, and several dozen units have been in operation for many years.

- If proper precautions are taken to exclude hazardous material, the emissions from microwave units are minimal.

- There are no liquid effluents from the Sanitec microwave unit.
- The internal shredder reduces waste volume up to 80%.
- The technology is automated and easy to use. It requires one operator.

The disadvantages include the following:

- If hazardous chemicals are in the waste, these toxic contaminants are released into the air or remain in the waste to contaminate the landfill.
- There may be some offensive odours around the microwave unit.
- The secondary shredder used for sharps is noisy.
- Any large, hard metal object in the waste could damage the shredder.
- The capital cost is relatively high.

EXAMPLES OF MICROWAVES SYSTEMS

Ecostéryl

The Ecostéryl process consists of grinding and heating wastes at the temperature of 100°C. The weight of waste is automatically checked, then it is packed into 750 litres containers and automatically handled and dumped into the hopper. The loading hopper includes a disinfectant spray system and a suction device to create a partial vacuum when it is opened. Treatment of air by washing, disinfecting, deodorising and filtration over activated charcoal, preserves the quality of rejected air. City water is fed through a non-return valve thereby preventing any fluid returning to the drinking water system. The liquid disinfectant (Dial Danios) is automatically dosed and pumped into the system.

Before the heat treatment phase begins, wastes are shredded by a knife mill with a grille to transfer waste into granules ranging in size from 1.5 to 2.0 cm. The mill's automatic control system includes an automatic anti-blocking device. After grinding, wastes are handled by screws and moisturised. The ground-up wastes are conveyed through an enclosed space and subjected to microwaves, which ensure in-depth heating and waste decontamination. The time of transfer into the treatment screw is on the order of 3 min. To improve disinfection level, waste is kept at a 500 litre buffer hopper for 1 hour. Disinfected wastes are then picked up under the holding hopper by an Archimedes screw and carried into a 45 litre hopper. Using the large exchange surface of the screw wastes are cooled to about 60 - 70°C. Volume of wastes is reduced by a factor of 5 and even more.

Several Ecostéryl medical waste decontamination units are used in France.

Capacity: 250 t/a.

Capital costs: 500 000 EUR.

Technical information: Temperature: 100°C; time of exposure: 60 minutes.

Stage of commercialisation: Commercialised.

Vendor's contact: AMB S.A., Avenue Wilson 622, 7012 Mons, Belgium; tel.: + 32 658 226 81, +32 658 247 98; amebo@skynet.be

Medister

The Austrian company Meteka supplies Medister units suitable for the decontamination of infectious waste using microwave action. The Medister 10, 60, and 160 types differ in the capacity of waste processed and allow various kinds of infectious waste to be disinfected. Medister 360 is designed to sterilise highly infectious material and waste from research laboratories using genetically modified organisms where perfect destruction of the biological agent is necessary.

Meteka also supplies a mobile microwave unit which consists of three Medister 160 waste disinfection devices. Within an 8 hour shift the unit may disinfect 36 Meditainer waste containers (2160 litres).

Medister HF is another waste sterilisation device and operates using domestic service water. Water, heated by high-frequency energy, is transformed into steam in the unit. The manufacturer specifies that the equipment is efficient in destroying *Bacillus stearothermophilus* spores exceeding 10^6 ($6 \log_{10}$).[9]

Capacity: 6-60 l/cycle.

Capital costs: 10 000 - 70 000 EUR.

Technical information: Temperature: 110/121/ 134°C; one operational cycle: 45 minutes.

Stage of commercialisation: Commercialised, in operation since 1991.

Vendor's contact: Burgasse 108, 8750 Judenburg, Austria, tel: +43 3572 85166, fax: +43 3572 85166 6, info@meteka.com, www.meteka.com

Sanitec

Sanitec microwave system consists of an automatic charging system, hopper, shredder, conveyor screw, steam generator, microwave generators, discharge screw, secondary shredder ("particliser"), and controls. The equipment includes hydraulics, high efficiency particulate air filter (HEPA), and microprocessor-based controls protected in an all-weather steel enclosure.

According to the manufacturer's information two Sanitec units are installed in the Chase Farm Hospital in Enfield, Middlesex, and operated by Polkacrest / LondonWaste. The yearly capacity of these two plants is 3600 tonnes. In addition to Enfield there are other units installed in Great Britain. Sanitec is certified for operation in the following European countries: France, Germany, Ireland, Great Britain, Spain, and Switzerland. Outside Europe, Sanitec plants are installed in: Australia, Brazil, Canada, USA, India, Japan, Kuwait, Philippines, Saudi Arabia, South Africa, and South Korea.

Capacity: 100 - 480 kg/h.

Capital costs: 420-500 000 EUR.

Technical information: Temperature: 95 - 100°C; exposure time: 30 minutes.

Stage of commercialisation: Commercialised, since 1990.

Vendor's contact: Sanitec Group LLC, 59 Village Park Road, Cedar Grove, NJ 07009, USA, tel.: +1 973 227 8855, fax: +1 973 227 9048

Sintion

Sintion is a microwave unit intended for a small waste quantity. It can be installed near the place of waste origin.

Waste is put in a vapour-permeable bag that allows steam to penetrate to the waste. Double bags or closed containers should not be used; puncture-resistant containers for sharp objects should not be hermetically closed. The operator opens the cover and inserts a bag filled with waste into the disinfecting chamber (one bag per cycle). The waste surface is exposed to the action of the steam, and the microwave radiation heats the waste from inside, destroying micro-organisms.

The temperature in the disinfecting chamber is 121°C and, if required, can be increased to 134°C. The period of the microwave radiation action can also be set to individual requirements. The disinfecting process usually lasts 10 to 30 minutes depending on the temperature selected.

After the end of the disinfecting cycle waste can be taken out and processed further in a crusher or in a compactor.

The Sintion unit was tested and accepted as suitable technology by the Robert Koch Institute in Germany, received a TÜV certificate in Austria, and was authorised for use in New York, USA. On its internet pages the company also refers to other tests performed and certificates obtained in other countries.[10]

Capacity: Up to 35 kg/h.

Capital costs: 50 000 EUR.

Technical information: Temperature: 121/134°C; pressure: 1/2 bar; time of exposure: 10-20 minutes.

Stage of commercialisation: Commercialised, in operation since 1995.

Vendor's contact: CMB Maschinenbau und Handels GmbH, Plabutscherstr. 115, 8051 Graz, Austria, tel.: +43 316 685 515-0, fax: +43 316 685 515-210, cmb@christof-group.at, www.christof-group.at

Sterifant 90/4

Wastes are collected in specially designed, reusable, hermetically sealed polycarbonate bins. The bins designed for the system are reusable up to 500 times. The lids are reusable by replacement of the "bung" after each treatment. The bin has a sealing clamp ring placed over the lid joint and locked shut forming a hermetic seal. The full and sealed bins can be easily stacked.

For each cycle 10 bins are put into sealed treatment chamber. The cycle begins with 10 hollow needles being lowered into the lids of the containers puncturing the "bung" seal of the lids. A washer around the hollow needles then forms a pressure seal, connecting each of the 10 bins to the system for treatment to begin.

At the start of the treatment cycle, approximately 2 litres of water and steam at 140°C are injected through the hollow needles into each of the bins. The system's nine microwave generators are then activated, heating the contents of the bins to a temperature in excess of 105°C, which is maintained, causing a saturated steam atmosphere. Creating first a vacuumed and then pressured atmosphere within each of the bins further increases the unit's effectiveness.

At the end of the cycle the treatment chamber of the unit opens automatically. Bins are then transferred to the integral shredder located at the side of the unit. The content of the bins is emptied automatically into the shredder. The shredded wastes are compacted at 80 bars pressure, and any liquid present is drawn off to the separate tank. The disinfecting process last about 70 minutes depending on the waste characteristics. The volume of wastes treated is reduced by up to 80%.

The system can be used as a mobile or static system for treatment of health care wastes on site. In Germany the Sterifant system was accepted in 1995, onto the approval list of the Robert-Koch Institute at the Ministry of Health.

Sterifant system units are used in Germany, Hungary, France, Netherlands, Italy, Spain, Great Britain, Bulgaria, Portugal.

Capacity: Approx. 125 kg/h.

Capital costs: 391 400 EUR (stationary), 446 400 EUR (mobile).

Technical information: Temperature: 95°C - 105°C; time of exposure: 70 minutes.

Stage of commercialisation: Commercialised since 1995.

Vendor's contact: Sterifant Vertriebs GmbH; 12, Rue Jean Engling, L-1466 Luxembourg; tel.: +352 43 22 22-1, fax: +352 42 60 59, sterilux@pt.lu, www.sterifant.com

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[1] K. Owen, K. Leese, L. Hodson, R. Uhorchak, D. Greenwood, D. Van Osdell, and E. Cole. "Control of Aerosol (Biological and Nonbiological) and Chemical Exposures and Safety Hazards in Medical Waste Treatment Facilities." (Cincinnati, OH: National Institute of Occupational Safety and Health, November 1997).

[2] See for example: J.L. Lauer, D.R. Battles, and D. Vesley, "Decontaminating infectious laboratory waste by autoclaving," *Appl. Envron. Microbiol*., 1982, 44 (3), 690-694; W.A. Rutala, M.M. Stiegeland, and F.A. Sarubbi, Jr., "Decontamination of laboratory microbiological waste by steam sterilization," *Appl. Environ. Microbiol*., June 1982, 43, 1311-1316. E. Hanel, Jr., "Chemical Disinfection" in *Control of Biohazards in the Research Laboratory*, Course Manual, School of Hygiene and Public Health, Johns Hopkins University, Baltimore, MD, 1981; Herman Koren, *Environmental Health and Safety*, Pergamon Press, NY, 1974.

[3] Based on information from www.ecodas.com

[4] Based on information leaflets: Mobile disposal of infectious waste, Maschinenvertrieb für Umwelttechnik, GmbH, Germany.

[5] Evaluation of the ABB Sanitec Microwave Disinfection System for Aerosol Emissions, North American Laboratory Group, New Britain, CT, 1992; ABB Sanitec Microwave Disinfection System - Ability to Control Aerosol Emissions: Synopsys of Evaluation, a summary of aerosol emissions studies provided by Sanitec, November 1, 1996.

[6] E. Cole. "Chemical and Biological Exposures and Safety Hazards in Medical Waste Treatment Facilities: An Assessment of Alternative Technologies." Vol. 98/2, No. 9 (Cedex, France: International Healthcare Waste Network (IhcWaN), August 31, 1998).

[7] Copy of "ABB Sanitec Microwave Disinfection System Laboratory Test Results" from North American Laboratory Group and Stanford University, provided by Sanitec.

[8] G.R. Vela and J.F. Wu, *Appl. Environ. Microbiol*., 37(3), 552, 1979; L. Najdovski, A.Z. Dragas, and V. Kotnik, *J. Hosp. Infect*. (19), 239, 1991.

[10] http://www.christof-group.at/www/en/cmb/zertifikate.php

Chapter 6

Low-heat thermal technologies – dry heat systems

Just as circulating hot-air ovens have been used to sterilise glassware and other reusable instruments, the concept of dry heat disinfection has been applied to treatment of medical waste. In dry heat processes, heat is applied without adding steam or water. Instead, the waste is heated by conduction, natural or forced convection, and/or by thermal radiation. In force convection heating, air heated by resistance heaters or natural gas, is circulated around the waste in the chamber. In some technologies, the hot walls of the chamber heat the waste through conduction and natural convection. Other technologies use radiant heating by means of infrared or quartz heaters. As a general rule, dry heat processes use higher temperatures and shorter exposure times than steam-based processes, but the time-temperature requirements actually depend on the properties and size of the objects being treated.

The toroidal mixing bed dryer using high velocity heated air (a technology designed for hospitals and offered by KC MediWaste) and the Demolizer (a small table-top device for hospital departments, clinics, medical offices, and other small volume generators) are two examples of dry heat systems in use, mainly in the USA.

OVERVIEW OF THE TECHNOLOGY

KC MediWaste System evolved out of efforts by Cox Sterile Products, Inc. to develop a rapid dry heat sterilizer coupled with their adaptation of the Torbed technology by Torftech (UK), a dry heat technology used in the processing of minerals, foods, and wastes. The first installation of the KC MediWaste technology is at the Mercy Health Center in Laredo, Texas.

The heart of the system is an air-tight stainless steel chamber into which shredded medical waste is introduced and exposed to high velocity heated air pumped into the bottom of the chamber through a ring of vanes or slots similar in design to turbine blades. The hot air is directed in a way that causes the waste particles to rotate turbulently around a vertical axis in a toroidal mixing action. Under these conditions, high rates of heat transfer take place. Within four to six minutes, dry unrecognisable waste is ejected. The waste can then be disposed of at a regular landfill.

HOW IT WORKS

The operation of the KC MediWaste System is as follows:

- *Waste loading*: Red bags are loaded into carts that attach to a lifter-dumper which automatically opens an air-lock hopper door and empties the waste into the shredder hopper while maintaining a negative pressure to minimise aerosolisation.

- *Internal shredding*: The waste is shredded to a relatively uniform size of about 19 mm, passing through a changeable screen and collected in a surge vessel.

- *Metering*: A gate valve controls the amount of waste introduced into the chamber. This opens automatically when the chamber is empty allowing a new batch to be processed. The chamber operates under a negative pressure.

- *Dry heat treatment*: After the shredded waste is pulled into the chamber it is exposed to high-velocity heated air (at about 171°C). The temperature in the chamber drops initially but recovers in about four minutes.

- *Discharge*: At the end of a pre-set time, the dump door of the chamber is opened expelling the waste in a matter of seconds. The treated waste falls into a compactor dumpster under the chamber.

- *Compaction and disposal*: The dry, unrecognisable waste is compressed and put into sealed containers ready for disposal at a sanitary landfill.

TYPES OF WASTE TREATED

The types of waste treated in the KC MediWaste System are somewhat similar to those treated in autoclaves or microwaves: cultures and stocks, sharps, materials contaminated with blood and body fluids, isolation and surgery wastes, laboratory wastes (excluding chemical waste), and soft wastes (gauze, bandages, drapes, gowns, bedding, etc.) from patient care. In addition, liquids such as blood and body fluids can also be treated in the unit. It is technically possible to treat human anatomical wastes but ethical, legal, cultural, and other considerations preclude their treatment in this technology.

Volatile and semi-volatile organic compounds, chemotherapeutic wastes, mercury, other hazardous chemical wastes, and radiological wastes should *not* be treated in a dry heat system.

EMISSIONS AND WASTE RESIDUES

Exhaust gases from the air pulled from the shredder hopper are filtered through a high efficiency particulate air filter (HEPA) and a carbon filter to remove aerosolised pathogens and odours prior to discharge. The hot air from the chamber is cooled in a venturi scrubber which also removes particulates. There are some odours in the vicinity of the unit.

The conditions in the chamber do no support combustion. Therefore, the air emissions are minimal as long as waste streams are properly segregated to prevent hazardous chemicals from being fed into the chamber.

The waste residue is dry and unrecognisable. With shredding and compaction, the waste volume is reduced by about 80% and has been accepted for disposal at a regular landfill. The mass of the dry treated waste is also reduced depending on the amount of moisture it had contained.

MICROBIAL INACTIVATION

Microbiological tests using *B. subtilis var. niger* strips (the variety traditionally used to test for dry heat resistance) introduced into the chamber showed a 6 $\log_{10}$ kill in about three minutes.[1]

ADVANTAGES AND DISADVANTAGES OF THE TECHNOLOGY

Heated air technology has the following advantages:

- The basic design of the treatment chamber is simple (it has been described as a 'popcorn' popper). The Torbed itself has been used for many years in other applications.
- If proper precautions are taken to exclude hazardous material the emissions from the dry heat system are minimal.
- The technology can treat waste with varying moisture content including blood and body fluids.
- There are no liquid effluents.
- The internal shredder and post-treatment compactor reduce waste volume by about 80%.
- The technology is automated and easy to use requiring only one operator.
- A combination of HEPA, carbon filters and a venturi scrubber keep odours to a minimum.
- The treated waste is dry, unrecognisable, and compact.

The disadvantages include the following:

- If hazardous chemicals are in the waste, these toxic contaminants are released into the air or remain in the waste to contaminate the landfill.
- Some slight odours may be generated near the compactor.
- Any large, hard metal objects may interfere with the shredder.
- The KC MediWaste Processor is a relatively new technology.

[1] Data provided by KC Mediwaste.

Chapter 7

Chemical based technologies

In the past, the most common chemical disinfectants for treating medical waste were chlorine-based because of the ability of chlorine and hypochlorite to inactivate a broad range of micro-organisms. Solutions of sodium hypochlorite (bleach) were regularly used. In recent years however, concerns have been raised about small amounts of toxic by-products associated with the use of large quantities of chlorine and hypochlorite (such as in the pulp and paper industry). Apparently, no studies have been done to establish whether or not this problem exists downstream of chemical treatment facilities for medical waste. It is believed however, that reactions between chlorine/hypochlorite and organic matter produce trihalomethanes, haloacetic acids, and chlorinated aromatic compounds that are toxic.

Sodium hypochlorite (NaOCl), a commonly used disinfectant in health care facilities, is manufactured by reacting chlorine with sodium hydroxide and water. Household bleach is a 3% to 6% concentration of sodium hypochlorite. It is effective in inactivating bacteria, fungi, and viruses, and in controlling odour. It is used extensively as a disinfectant for drinking water, swimming pools, and sewage treatment. Not surprisingly, it was one of the first chemical disinfectants to be used in treating medical waste.

Recently, non-chlorine chemical disinfectants have been introduced into the market, such as peroxyacetic acid (also known as peracetic acid), glutaraldehyde, sodium hydroxide, ozone gas, and calcium oxide. Some of these are commonly used in disinfecting medical instruments.

Calcium oxide, also called lime or quicklime, is a white or grey odourless powder produced by heating limestone. It has a myriad of uses in medicines, water softeners, cements, glass making, purifying sugar, and treating soils. It reacts with water to form calcium hydroxide and can irritate the eyes and upper respiratory tract. The US NIOSH recommended exposure limit is 2 mg/m^3.

Ozone is an oxidising agent that contains three atoms of oxygen (O_3) rather than the usual two (O_2). Trace amounts of ozone are formed by the sun or when lighting strikes. It is a component of smog and also makes up a protective layer around the earth. Because it is highly reactive, it breaks down easily back to its more stable form (O_2). Ozone is used in drinking water treatment, industrial and municipal wastewater treatment, odour control, air purification, agriculture, and food processing. Ozone can cause eye, nose, and respiratory tract irritation. According to US NIOSH, workplace air should not have more than 0.1 ppm of ozone.

Alkali or caustic, such as sodium or potassium hydroxide, are extremely corrosive. They are used in chemical manufacturing, pH control, soap production, cleaners, textile processing, and a wider range of other uses. Solid cakes or pellets of the alkali react strongly with water releasing heat. Contact with various chemicals including metals may cause fire. Concentrated alkaline solutions are corrosive enough to cause permanent scarring, blindness, or even death. Aerosols of the alkali can cause lung injury. The US NIOSH recommended exposure limit is 2 mg/m^3.

TYPES OF WASTE TREATED

The types of waste commonly treated in chemical-based technologies are: cultures and stocks, sharps, liquid human and animal wastes including blood and body fluids (in some technologies this may be limited to a certain percentage of the waste), isolation and surgery wastes, laboratory waste (excluding chemical waste), and soft wastes - gauze, bandages, drapes, gowns, bedding, etc., from patient care.

Ethical, legal, cultural, and other considerations preclude treatment of human anatomical wastes in chemical treatment systems.

Volatile and semi-volatile organic compounds, chemotherapeutic wastes, mercury, other

hazardous chemical wastes, and radiological wastes should *not* be treated in chemical treatment units. Large metal objects may damage internal shredders.

EMISSIONS AND WASTE RESIDUES

Since chemical processes usually require shredding, the release of pathogens through aerosol formation may be a concern. Chemical-based technologies commonly operate as closed systems or under negative pressure passing their air exhaust through HEPA and other filters. These safeguards should not be compromised. Another issue relates to occupational exposures to the chemical disinfectant itself through fugitive emissions, accidental leaks or spills from storage containers, discharges from the treatment unit, volatilised chemicals from treated waste or liquid effluent, etc. Chemical disinfectants are sometimes stored in concentrated form thus increasing the hazards.

MICROBIAL INACTIVATION

Micro-organisms vary in their resistance to chemical treatment. The least resistant are vegetative bacteria, vegetative fungi, fungal spores, and lipophilic viruses. The more resistant organisms are hydrophilic viruses, mycobacteria, and bacterial spores such as *B. stearothermophilus.* Tests of microbial inactivation efficacy should be conducted to show that a 10^4 kill or greater of at least *B. stearothermophilus* spores is achieved at the chemical concentrations and treatment conditions of normal operation of the technology.

ADVANTAGES AND DISADVANTAGES OF THE TECHNOLOGY

Chemical treatment technologies have the following advantages:

- The technologies using sodium hypochlorite have been used since the early 1980s and have a long track record. The process is well understood.
- The technologies are well automated and easy to use.
- Liquid effluents generally can be discharged into the sanitary sewer.
- No combustion by-products are produced.
- If the technology incorporates shredding, the waste is rendered unrecognisable.

The disadvantages include the following:

- There are concerns of possible toxic by-products in the wastewater from large-scale chlorine and hypochlorite systems.
- Chemical hazards are a potential problem with chemical-based systems.
- If hazardous chemicals are in the waste, these toxic contaminants are released into the air and wastewater, remain in the waste to contaminate the landfill, or they may react with the chemical disinfectant forming other compounds that may or may not be hazardous.
- Noise levels, such as from a hammermill process or a shredder, can be very high.
- There may be some offensive odours around some chemical treatment units.
- Any large, hard metal object in the waste can damage mechanical devices such as shredders.

EXAMPLES OF CHEMICAL BASED TECHNOLOGIES

Newster

The Newster is a machine designed for small and medium hospitals. Technology combines thermal and chemical processes to sterilise waste.

In a closed sterilisation vessel a powerful rotor fitted with blades agitates, disintegrates and heats the wastes by impact and friction. The wastes are sprayed with 14% – 15% strength NaClO. When the temperature reaches the predetermined level of 150°C, the mass of wastes is automatically sprayed with brief injections of water so that the temperature remains above 150°C for around two minutes.

During the process, the high temperature melts plastic materials and the wastes are transformed into granules of a uniform grayish-brown colour, with average dimensions of 2 – 3 mm.

The treated wastes are then cooled down to 95°C at which point the cycle has been completed and wastes, by now sterile, are automatically unloaded. The whole process lasts around 20 minutes.

The vapours released by the evaporation of liquids are absorbed by a flow of water containing sodium hypochlorite inside a column connected to the sterilisation vessel. To disperse the heat produced by the system, part of the water is continuously replaced by fresh water from the main supply. Excess water and incondensable gases are discharged into the sewers.

The use of chlorine-based disinfectants can cause a risk of chloride's presence in the waste decontaminated, and the creation of the new toxic chlorine compounds (i.e. trihalomethane).

Capacity: 370 t/a.

Capital costs: 85 000 EUR.

Technical information: Temperature: 95 - 155°C; time of exposure: 25 minutes; amount of NaClO use per cycle: 0.3 – 0.5 kg.

Stage of commercialisation: Commercialised.

Vendor's contact: Multiservice First s.r.l.; Via dei Boschetti 58/A, 47893 Borgo Maggiore, Republic of San Marino; tel.: +378 0549 907 222, fax +378 0549 907223, First@omniway.sm, www.tradecenter.sm/newster/

Waste Reduction By Waste Reduction, Inc.[1] or WR[2]

Waste Reduction by Waste Reduction Inc., offers an alkaline digestion process to convert animal and microbial tissues into a neutral, decontaminated, aqueous solution. The WR[2] process utilises alkaline hydrolysis at elevated temperatures. The alkali also destroys fixatives in tissues and various hazardous chemicals including formaldehyde and glutaraldehyde.[2]

The Tissue Digester is an insulated, steam-jacketed, stainless steel tank with a retainer basket for bone remnants and a clam-shell lid. After the waste is loaded in the hermetically sealed tank, alkali in amounts proportional to the quantity of tissue in the tank is added along with water. The contents are heated, usually to between 110° to 127°C or up to about 150°C, while being stirred. The tanks are rated at 6.1 bar but are operated at less than 4.8 bar Depending on the amount of alkali and temperature used, digestion times range from three to six hours. The technology does not handle the full range of waste streams in a health care facility, but is designed for tissue wastes including anatomical parts, organs, placentas, blood, body fluids, specimens, degradable bags, degradable fabrics (such as Isolyser's Orex and Enviroguard), and animal carcasses. Antineoplastic (cytotoxic) agents can also be destroyed by the strong alkali.

Capacity: 15 – 4500 kg/cycle.

Capital costs: 100 000 – 830 000 EUR.

Technical information: Temperature: 110 - 127 (150) °C; pressure: 4.8 bar; time of exposure: 3 - 6 hours.

Stage of commercialisation: Commercialised in the US since 1993; awaits approval for the EU market.

Vendor's contact: Waste Reduction by Waste Reduction Europe Ltd.; Clydebank Riverside Medi-Park, Beardmore Street, Clydebank, Glasgow G81 4SA, UK; tel.: +44 141 951 5980, fax: +44 141 951 5985; wreurope@wreurope.com; www.wreurope.net

Steris EcoCycle 10[3]

It is a compact system designed to treat small volumes and can be used at or near the point of generation of waste. It treats 2 to 4 kg of waste every 10 minutes including syringes, needles, glassware, laboratory waste, blood, other body fluids, specimens, cultures, and other contaminated materials.

The waste is collected in a portable processing chamber at the point of generation. When filled, the chamber is transported to a processor using an optional caddy. A peracetic acid-based decontaminant in a single-use container is dropped into the chamber (the specific formulation used depends on how much fluid is in the waste). As the processing cycle begins, the material is groundup breaking the decontaminant vial and chemically disinfecting the waste in 10 - 12 minutes. The processing cap contains a replaceable HEPA filter to prevent the escape of aerosolised pathogens. At the end of

the cycle, the chamber is put on a tilt bracket and its contents are dumped into the liquid separation unit. Water is used to rinse the waste. The liquid effluent is filtered before being discharged into the sewer drain, while the waste is retained in the liquid separation unit for disposal as regular trash. The chemical by-products of the decontaminant are acetic acid and some hydrogen peroxide which eventually break down into a weak vinegar solution. Microbial inactivation tests[4] demonstrate a 6 to 8 $\log_{10}$ kill for 13 micro-organisms including *B. subtilis*, *Staphylococcus aureus, Pseudomonas aeruginosa*, bacteriophage MS-2, *Mycobacterium bovis*, Poliovirus, *Aspergillus fumigatus, Candida albicans*, and *Giardia muris*. Steris markets its decontaminant in two doses: STERIS-SW mainly for solid wastes with low organic load, and STERIS-LW for waste with high amounts of liquids and a high organic load.

Capacity: 12 – 24 kg/h.

Capital costs: 16 000 EUR.

Technical information: Time of exposure: 12 minutes.

Stage of commercialisation: Commercialised.

Vendor's contact: 5960 Heisley Road, Mentor, Ohio 44060-1834, USA; tel.: +1 440-354-2600, fax: +1 440 639 4450; www.steris.com

OTHER SYSTEMS

Not included in this report are technologies that use chemical compounds not necessarily for their disinfecting potential, but for their ability to solidify or encapsulate waste. Some encapsulating agents are fast-acting acrylic or epoxy-based polymers incorporating anti-microbial agents to disinfect the waste. Many claim to be non-toxic and to reduce bio-hazardous fluids into non-hazardous materials.

Health care facilities interested in these technologies should ask for the results of microbial inactivation efficacy tests, toxicity tests, occupational exposure tests, etc. to ascertain claims that the resulting solidified waste is indeed disinfected and non-hazardous. Because organic material in liquid medical waste can reduce anti-microbial effectiveness, tests for disinfection should be conducted using 100% serum at the use dilution specified on the product label. Interested facilities should also check whether the solidifying and sanitising agents are themselves hazardous substances and whether the resulting encapsulated waste can be disposed in a landfill. However, although such waste can be considered as 'treated', it may still have infectious properties and hence cannot be landfilled according to the European Union legislation (Directive 99/31/EC).

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[1] Based on vendor website, brochures and technical data provided by WR².

[2] Data provided by Dr. Gordon Kaye, WR².

[3] Based on vendor website, literature provided by Ecomed beginning in 1993 and by Steris from 1995 to 1999, and personal communications with various Steris personnel.

[4] W.L. Turnberg. *Biohazardous Waste: Risk Assessment, Policy and Management.* (New York, NY: John Wiley & Sons, Inc. 1996).

Chapter 8

Irradiation, biological and other technologies

This chapter discusses other technologies that use irradiative and biological processes. The presentation on irradiation technology focuses on electron beam systems. There have been very few biological systems designed for medical waste treatment as this technology is still in the research and development phase. Because occupational injuries from needles and syringes are a problem in health care facilities, a discussion of sharps waste treatment technologies is presented at the end of this chapter. Sharps technologies are small portable units that operate on the principles of thermal or chemical treatment.

Irradiation Technologies

OVERVIEW OF THE TECHNOLOGY

When electromagnetic radiation has high enough energy to knock out electrons from their atomic orbits, it is referred to as **ionising radiation**; examples are x-rays and gamma rays. (**Non-ionising radiation**, such as microwaves and visible light, do not have sufficient energy to remove electrons.) If ionising radiation interacts with a cell, its main target is the DNA in the nucleus. At sufficiently high doses of ionising radiation, extensive damage is done to DNA leading to cell death. The ionising radiation also creates so-called free radicals that cause further damage by reacting with macromolecules in the cell (e.g., proteins, enzymes, etc.). Ionising radiation can be obtained using radioactive materials, such as **Cobalt-60**, that emit high-speed gamma rays. **UV-C** or ultraviolet radiation in the C range (253.7 nm), also known as germicidal or short wave UV, is another kind of ionising radiation that can destroy cells under the proper conditions. UV-C can be generated using special lamps and has been employed as a supplement to alternative treatment technologies to inactivate aerosolised pathogens from shredders and other mechanical devices.

Another technique for producing ionising radiation is to use an "electron gun" from which a beam of high-energy electrons is propelled at high speed to strike against a target. A product of the nuclear and defence industries, electron beam (or e-beam) technology has been around for a few decades. It is also used in other applications, such as polymer processing, tyre manufacturing, and sterilisation of medical products. Unlike cobalt-60, e-beam technology does not use radioactive sources and has no residual radiation once the e-beam system is turned off. One area of debate, however, is the issue of induced radioactivity. E-beam manufacturers argue that radioactivity cannot be induced unless very high energies are used, e.g., above 10 or 16 MeV (mega-electronvolts). Others have stated that low levels of radioactivity may be induced at much lower energies. This argument has arisen in the context of the public controversy over food irradiation using e-beam technology.

HOW IT WORKS

Electron beam technologies are highly automated and computer controlled. In general, e-beam systems consist of a power supply; a beam accelerator where the electrons are generated, accelerated, and directed towards the target; a scanning system which delivers the required dose; a cooling system to cool the accelerator and other assemblies; a vacuum system to maintain a vacuum in the accelerator; a shield to protect workers; a conveyor system to transport the waste; and sensors and controls. The shielding system could be in the form of a concrete vault, an underground cavity, or an integral shield around the treatment area. E-beams do not alter the physical characteristics of the waste except perhaps to raise the temperature a few degrees. As such, e-beam technologies require shredders or other mechanical device in the post-processing stage to render the waste unrecognisable and reduce waste volume.

TYPES OF WASTE TREATED

The types of waste commonly treated in an e-beam technology equipped with a mechanical destruction process are: cultures and stocks, sharps, materials contaminated with blood and

body fluids, isolation and surgery wastes, laboratory waste (excluding chemical waste), and soft wastes (gauze, bandages, drapes, gowns, bedding, etc.) from patient care. Ethical, legal, cultural, and other considerations preclude treatment of human anatomical wastes.

Volatile and semi-volatile organic compounds, chemotherapeutic wastes, mercury, other hazardous chemical wastes, and radiological wastes should *not* be treated in e-beam units.

EMISSIONS AND WASTE RESIDUES

E-beam systems do not create any pollutant emissions except possibly for small amounts of ozone which breaks down to diatomic oxygen (O_2). The residual ozone helps remove odours and contributes to the disinfection process in the treatment chamber, but it should be converted back to diatomic oxygen before being released into the environment or workspace.

MICROBIAL INACTIVATION

Bacteria exhibit varying degrees of resistance to radiation depending in large part on their ability to repair damage to their DNA from irradiation. Depending on the dose, bacterial cells may not be killed outright but their ability to reproduce is impaired. *B. stearothermophilus* and *B. subtilis* spores have been recommended for demonstrating microbial inactivation by irradiation. However, *B. pumilus* spores are more resistant to irradiation and have been used as a standard biological indicator in the sterilisation of medical products by irradiation. Other biological indicators even more resistant to radiation, such as *Deinococcus radiodurans*, can provide a very stringent measure and add a margin of safety if needed.

ADVANTAGES AND DISADVANTAGES OF THE TECHNOLOGY

E-beam treatment technologies have the following advantages:

- The basic technology has been used in other applications for about two decades and is familiar to hospital staff involved in cancer therapy.
- E-beam technology does not produce any toxic emissions (except for small amounts of ozone) and there are no liquid effluents.
- Unlike cobalt-60, there is no ionising radiation after the machine is turned off.
- It is a room-temperature process and nothing is added to the waste – no steam, water, chemicals, heated air, etc.
- The technology is well automated and requires little operator time.
- The e-beam technology itself (i.e., excluding shredders or compactors) is noiseless.
- It has a low operating cost.

The disadvantages include the following:

- Personnel must be protected from radiation exposure.
- If an integral shield is not part of the design, the e-beam system requires a concrete shield several feet thick or an underground structure, either of which adds significantly to the installed capital cost.
- Ozone off-gas needs to be removed before the exhaust is released to the atmosphere.
- In relation to food irradiation. Some groups have raised the possibility that low-levels of radioactivity may be induced. This is an area that needs more investigation.
- The basic technology does not reduce waste volume or make the waste unrecognisable unless a shredder or other mechanical device is added as a post-treatment step.
- Any large, hard metal object in the waste can damage any shredder or grinder.

The University of Miami's Laboratories for Pollution Control Technologies,[1] in association with the UM/Jackson Memorial Medical Center, have developed a high-energy electron beam medical waste treatment facility. This e-beam facility is capable of treating 180 kg per hour of medical waste and uses 0.19 m^2 of space including shielded vault, control room, and waste holding area.

Biological Systems

Bio Conversion Technologies Inc.[2] (BCTI), a division of Biomedical Disposal, Inc., is developing a medical waste treatment system using biological processes. A prototype of the

"Bio-Converter" has been tested in Virginia. It uses an enzyme mixture to decontaminate medical waste and the resulting sludge is put through an extruder to remove water for sewage disposal. The technology is suited for large applications (10 tons/day) and is also being developed for use in the agricultural sector to break down animal waste.

Small Sharps Treatment Units

Occupational injuries from needles and syringes are a problem facing all health care providers. It has been estimated that 600 000 to 800 000 nurses, physicians and other health care workers suffer needle stick and other percutaneous injuries due to sharps. Not all injuries result in infections but the transmission of bloodborne diseases from contaminated sharps is always a possibility. Three diseases in particular — Hepatitis C virus (HCV), Hepatitis B virus (HBV) and human immunodeficiency virus (HIV) — are of great concern. Most of these injuries can be prevented by the use of safer devices such as needleless systems, devices with retractable or blunt needles, or other so-called safe needle devices with built-in safety features.

Another way of helping to reduce the risk of needle sticks is by using sharps waste treatment technologies near the point of use.

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[1] Based on technical data provided by the university's Laboratories for Pollution Control Technologies, newspaper clippings, data provided by Dean Brown, site evaluation of the unit at the University of Miami-Coral Gables, and personal communications with Thomas Waite and Charles Kurucz.

[2] Based on personal communications and materials provided by Michael Chelette in 1999.

Chapter 9

Factors to consider in selecting a non-incineration technology

Determining the best technology or combination of technologies for a particular facility depends on many site-specific factors. These include the amount and composition of waste generated, available space, regulatory approval, public acceptance, and cost. Some key factors to consider are listed in Table 9-1 and discussed in this chapter.

Table 9-1. Factors to consider in selecting a technology

- ✓ Throughput capacity
- ✓ Types of waste treated
- ✓ Microbial inactivation efficacy
- ✓ Environmental emissions and waste residues
- ✓ Regulatory acceptance
- ✓ Space requirements
- ✓ Utility and other installation requirements
- ✓ Reduction of waste volume and mass
- ✓ Occupational safety and health
- ✓ Noise and odour
- ✓ Automation
- ✓ Reliability
- ✓ Level of commercialisation
- ✓ Technology manufacturer/vendor background
- ✓ Cost
- ✓ Community and staff acceptance

THROUGHPUT CAPACITY

Having determined the rate of waste generation for the different waste streams and having implemented a vigorous waste minimisation plan, the health care facility is now in a position to select a non-incineration treatment technology appropriate for the types and amount of waste to be treated. When matching throughput capacities with waste generation rates, the facility should take into account future anticipated growth and variables in waste generation.

TYPES OF WASTE TREATED

Broad categories are used to describe the types of waste that a technology can handle, generally based on manufacturers' recommendations. After determining what goes in a red bag, facilities should make sure that the selected technology can indeed treat each waste category from the perspective of mechanical destruction, microbial inactivation, emissions, regulatory acceptance, and safety.

The use of monitoring equipment, such as devices to detect low-level radioactive waste, can help keep specific waste streams out. Some technology vendors offer monitoring devices to exclude unwanted materials from the input stream. Others design their equipment to be able to interface with such devices.

MICROBIAL INACTIVATION EFFICACY

The main purpose for the treatment technology is to decontaminate waste by destroying pathogens. Facilities should make certain that the technology can meet state criteria for disinfection. Many countries require approval of alternative technologies based on microbiological inactivation efficacy. A consortium of state regulatory agencies called the (US) State and Territorial Association on Alternative Treatment Technologies (STAATT) met in 1994 and 1998 to develop consensus criteria for medical waste treatment efficacy. The first STAATT meeting came up with the following definitions of the levels of microbial inactivation:

Level I Inactivation of vegetative bacteria, fungi, and lipophilic viruses at a 6 $\log_{10}$ reduction or greater;

Level II Inactivation of vegetative bacteria, fungi, lipophilic/hydrophilic viruses, parasites, and mycobacteria at a 6 $\log_{10}$ reduction or greater;

Level III* Inactivation of vegetative bacteria, fungi, lipophilic/hydrophilic viruses, parasites, and mycobacteria at a 6 $\log_{10}$ reduction or greater; and inactivation of *B. stearothermophilus* spores and *B. subtilis* spores at a 4 $\log_{10}$ reduction or greater;

Level IV Inactivation of vegetative bacteria, fungi, lipophilic/hydrophilic viruses, parasites, and mycobacteria, and *B. stearothermophilus* spores at a 6 $\log_{10}$ reduction or greater.

* Level III was selected as the recommended minimum criteria by STAATT.

A 6 $\log_{10}$ reduction (or a 10^6 kill) is equivalent to a one millionth survival probability in a microbial population or a 99.9999% reduction of the given micro-organism as a result of the treatment process. Selected pathogen surrogates representing the above-mentioned micro-organisms are used in testing. The following representative biological indicators were recommended at the second STAATT meeting ("ATCC" refers to the American Type Culture Collection).

ENVIRONMENTAL EMISSIONS AND WASTE RESIDUES

Facilities should consider discharges or emissions (including fugitive emissions) to all possible environmental media – workplace air, outside air, waste residues, wastewater, landfills, etc. – and select technologies with the least impact on the environment. Facilities may be able to obtain data from state regulators regarding any past permit violations by others using the technology.

Chapter 10

Economics of treatment technologies

CAPITAL COSTS

Total capital cost should include all direct and indirect costs related to siting and installation as well as the equipment purchase cost. Some technologies require little site preparation and installation, while others involve significant installation requirements. The following list gives examples of direct costs that need to be taken into account. Not all of these items necessarily apply to a given technology.

- Site preparation
- Demolition and disposal (e.g. removal of an old incinerator)
- Building (new construction or renovation)
- Foundation and supports
- Electrical service
- Piping including steam and water lines
- Heating and ventilation system
- Air compressor
- Lighting
- Sanitary sewer
- Sprinkler system
- Painting and insulation
- Handling and on-site fabrication
- Equipment purchase cost (including auxiliary devices, instrumentation, carts for transporting waste, monitoring equipment, freight, sales tax, etc.).

The following are examples of indirect costs that should be considered:

- Project management
- Engineering
- Construction fees
- Permitting
- Regulatory testing
- Professional fees (including media fees to respond to public outcry, if the community does not like the technology choice)
- Start-up
- Performance testing
- Contingencies.

There are intangible costs, such as loss of good public perception if the chosen technology is unpopular in the community or among staff that cannot be quantified.

ANNUAL OPERATING COSTS

Annual operating costs are costs incurred every year due to the operation of the technology during the life of the equipment. Due to inflation, the magnitude of these costs may vary, but the same kinds of costs will be incurred. Direct costs are those that are dependent on the throughput of the system, such as:

- Labour (operating and supervisory)
- Utilities
  - Electricity
  - Steam
  - Natural gas
  - Water
  - Compressed air
  - Others
- Supplies
  - Boxes or containers
  - Autoclavable or steam permeable bags
  - Labels
  - Others
- Consumables
  - Chemical disinfectants
  - Electrodes or torches
  - Others
- Maintenance (scheduled and unscheduled)
  - Materials
  - Replacement parts (e.g, refractories, shredder blades, etc.)
  - Maintenance labour
- Landfill disposal costs (including transportation and tipping fees)

- Cost of disposing wastes not treated by the technology
- Cost of treating waste during scheduled and unscheduled downtime.

Indirect costs are costs that are not proportional to throughput, such as:

- Overhead
- Administrative costs
- Insurance
- Annual regulatory permit fees
- Periodic verification or emission tests
- Taxes.

INCINERATOR UPGRADE COSTS

With respect to incineration, cost is a major factor to consider in addition to the environmental, health, and other intangible issues raised in Chapter 1. For an old existing incinerator compliance with the new EU regulation for medical waste incinerators would likely require the installation of an expensive pollution control device, retrofit of the secondary chamber, and the addition of monitoring equipment, as well as periodic stack testing, operator training, etc. Therefore, capital cost items include:

- Purchase and installation of a wet scrubber or other device
- Secondary chamber retrofits
- Purchase and installation of monitoring equipment.

Components of annual operating costs include:

- Annual costs related to operation of a wet scrubber or other device
- Annual costs related to the secondary chamber
- Annual cost of stack testing
- Annual cost of parametric monitoring
- Annual cost of operator training course.

Appendix:
Non-incineration treatment technologies in Europe – case studies

The Centre Hospitalier in Roubaix, France

The capacity of the Centre Hospitalier in Roubaix is 2000 beds, with the production of 1 ton of waste (all types of waste) per bed annually. The composition of the waste in the hospital is following: Hazardous hospital waste - 15% (3% of which are anatomical parts and cytostatics, the rest is infectious waste), the remaining 85% is non-infection waste. This 85% is made up of special industrial waste 2%, ordinary industrial waste 3%, with the remaining 80% similar to household waste of which 45% is recyclable.

Before 1993, the hospital in Roubaix incinerated its waste without much segregation in an on-site incinerator. In 1993, they decided to shut down the incinerator, and looked for other possibilities how to treat the waste. They chose to pre-sort waste at the roots and to treat its infectious part on the spot, using a non-incineration method based on hot steam. In August 1993, the hospital bought Ecodas T1000 (a shredding-steam treatment-drying technology), and in 1995 another T1000 unit.

According to the hospital, Ecodas units were chosen as it seemed to be the best adapted to their needs: it's environmentally friendly, it decontaminates infectious waste using a steam based process at 138°C, and the internal shredder reduces the initial volume of waste by 80%. Collection and sorting waste on-the-spot was adopted in virtue of the principle of proximity: less manipulation of infection risk waste products implies less professional risks for staff at the hospital, and for workers that collect waste. This also obviously reduces transport costs.

Mr. Bernard Poulain, the director of the hospital in Roubaix evaluates the switch from an incineration to non-incineration method as follows:

> *"Our cost effective objectives have been met. Our waste management is economical; we have reduced the annual global cost of waste management at the hospital by 30%. We have improved risk control and we are more vigilant. Our approach is also more ecological."*

Hospital waste management in Portugal

Until 1995, environmentally sound hospital waste management in Portugal was virtually non-existent. Legislation divided hospital waste only in two categories: Non hazardous waste, and hazardous waste. There was a very weak source separation system and as a result 50% of the waste (25 000 t/year) was considered hazardous. The final destinations of the hazardous waste were 40 on-site medical waste incinerators. The environmental performance of these incinerators was very poor. The combustion chamber temperature of most of them was below 800°C. They didn't have any kind of flue gas treatment systems, and no air pollution monitoring was in place.

Due to the public pressure, in 1996 the Government approved a new legislation that finally allowed the autoclaving of infectious waste. In 1998 the Government approved the National Plan for Hospital Waste with the target of phasing out 30 existing incinerators, keeping only one or two incinerators for the whole country in 2000. In 2003 and 2004 two of the last three medical waste incinerators were closed. The remaining facility is now under a lot of public pressure to close because it doesn't have an official permit to operate.

The amount of hazardous hospital waste has been steadily decreasing since 1995 (25 000 t in 1995, 16 469 t in 2001, and 15 336 t in 2002) due to a better segregation of waste. Between 1996 – 1998 two big autoclaves were built, which nowadays treat more than 80% of the total hospital hazardous waste produced in Portugal. With only one remaining medical waste incinerator, the incineration of hospital waste dropped dramatically from 25 000 t in 1995, to 5726 t in 2001, and to 3174 t in 2002.

There is still room for further elimination of incineration of hazardous hospital waste. The legislation from 1996 categorises medical waste of group III and IV as hazardous. For category IV waste incineration is compulsory (the category III

waste could be autoclaved), therefore the correct separation of waste groups III and IV is essential. About 20% of hazardous hospital waste was incinerated in 2002, but the amount of Group IV waste represents only some 5% of the total waste in hospitals where a more serious segregation policy is in place (i.e. the District Hospital of Evora or The Hospital Prelada in Porto).

Ireland has decided to treat hospital waste by a non-incineration technology

Until recently, in Ireland approximately 50% of healthcare waste was incinerated on-site and 50% landfilled. With current trends both national and international there is considerable pressure on the healthcare sector to shut down hospital incinerators and find alternative ways of dealing with wastes. At the present time, there are only two hospitals with licensed incinerators, both of which have not been in operation for the past several years. It is anticipated that the last two medical waste incinerators will be unlicensed and dismantled following the 150 other incinerators that at one time existed in Ireland.

In a recent development, a joint Irish North/South Body, Joint Waste Management Board contracted Sterile Technologies Ireland, a private waste management company, for dealing with hospital waste in Ireland. Sterile Technologies Ireland use a STI Model 2000 process in shredding waste prior to treatment followed by the injection of steam that results in complete elimination of pathogenic micro-organisms. Key parameters are continuously monitored and recorded providing for a safe, clean and accountable process of healthcare waste. The unrecognisable waste is held pending verification and scientifically defined as sterile before sending to landfill.

The current position in Ireland is that 95% of all healthcare waste treated on the island receives segregation at source into specific disposal streams of domestic and medical waste. The medical waste is stored in wheeled bins at each hospital facility and transported with electronic tracking from its point of production to its final disposal.

This way of dealing with medical waste changed the perception that incineration was the only safe method for healthcare waste disposal. A detailed explanation of this new technology through workshops helped the introduction of the system to hospitals and aided segregation of waste at source, dealing with the documentation, dedicated collection points and the wheeled bins used at each facility.

The waste, which is not acceptable using the STI Model 2000 process, falls under two categories. Firstly, packaging that is not sealed properly, which is damaged, holed or leaking and packaging which does not have an identifiable cable tie attached and not labelled to denote source and contents. This category if managed can change and be processed. The second category is waste that cannot be processed using the STI Model 2000 processing system. Cytotoxic, sharp and non-sharp waste, recognisable anatomical waste i.e. limbs, organs, waste containing CJD or Hazard Group 4 pathogens, making approximately 3% of the overall medical waste in Ireland is exported under transfrontier shipping licence to an incineration outlet in Belgium.

Slovenia has treated infectious waste using hot steam mobile units since 1995

Until recently, according to the Slovenian regulation No. 1520 of 30/95 Collection of law issued by Ministry of Health, all infectious waste had to be dealt with the mobile equipment ZDA-M3 (mobile steam disinfection). There were 3 mobile units in Slovenia, which treated infectious waste. The decontaminated waste was consequently landfilled. Incineration was allowed only for other hazardous hospital waste categories such as anatomical parts, cytostatics, and pharmaceuticals.

In November 2003 a new law, regulating hospital waste in Slovenia was adopted. This includes a new waste catalogue based on EU legislation. The previous regulation from 1995, which ordered the use of non-incineration treatment technology, was cancelled resulting in both incineration and non-incineration technologies being legal for the treatment of infectious waste. At the moment infectious waste still undergoes non-incineration decontamination processes, and hopefully Slovenia, as a new member of EU, will follow the examples of its progressive EU neighbours and continue pursuing non-incineration technologies for the treatment of medical waste.

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