

BIOHAZARD

醫療廢物處理技術
方案檢討報告書

Review Of Alternative Technologies
For The Treatment Of Clinical Waste



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EXECUTIVE SUMMARY

Chapter

1

- 1.1** The inherent hazards of clinical waste generated from hospitals and clinics are pathogens and sharps. To reduce the risk to waste handlers and the public, clinical waste requires segregation, collection and proper treatment prior to disposal. While efforts have been made by the hospitals and clinics to reduce the quantity of clinical waste at source through waste segregation, a small quantity still requires special treatment and disposal. The present disposal of clinical waste at the landfills is far from satisfactory and we need to put in place a comprehensive control scheme and environmentally sound disposal arrangement.
- 1.2** The Government has examined various treatment options, and has made reference to the overseas practices before proposing high temperature incineration at the Chemical Waste Treatment Centre (CWTC) as the treatment and disposal option of clinical waste in Hong Kong. To address the concerns of the local residents, the Government has conducted an Environmental Impact Assessment (EIA) which confirms that the high temperature incinerator at the CWTC being fully equipped with pollution abatement systems can completely destroy the biohazardous nature of clinical waste and meet the stringent emission standards. The EIA findings have been consulted with the Advisory Council on the Environment and gained their support.
- 1.3** The proposal to incinerate clinical waste at the CWTC has also been consulted with the Kwai Tsing District Council, and in light of their concerns as well as the objection raised by the Green Peace, and at the request of the LegCo Joint Environmental Affairs and Health Services Panel, the Government has commissioned a review to re-visit the various treatment technologies.
- 1.4** Since the last review carried out by the EPD in 1993-94, alternative treatment technologies (mainly autoclaving, microwave treatment, and chemical disinfection) are becoming more common especially in some US states. However, incineration is still the predominant and most well proven technology adopted in Europe, Australia, and the Asian region such as Japan, Singapore, Malaysia, and Taiwan.
- 1.5** Contrary to the claims made by certain parties, these alternative technologies do generate both air and liquid emissions, and would equally require proper pollution abatement. Uncontrolled emissions of volatile organic compounds are especially problematic, and this would pose serious constraint if the equipment is installed at hospital settings. The use of shredders to enhance the effectiveness of treatment by these systems may also cause occupational health problems, since shredders are easily damaged by hard objects and during maintenance, the workers may get in direct contact with the infectious waste or exposed to microbial aerosols when the equipment is opened. Unlike incineration, there are very few

documented studies to identify and quantify the potential environmental and health hazards of these technologies, and hence they do not attract the same level of public attention and concerns.

- 1.6** Since these technologies are not able to treat clinical waste containing (or contaminated with) pharmaceuticals, cytotoxic drugs (which may be carcinogenic, mutagenic or teratogenic) and chemicals such as ointments in the swabs and dressings (which will end up as VOC emissions), more stringent waste segregation measures would have to be adopted. Human body parts also require separate arrangement for disposal since autoclave, microwave or chemical treatment is not compatible with cultural practices.
- 1.7** Waste segregation would help to reduce the volume of clinical waste requiring treatment, as well as to ensure that pharmaceuticals and chemicals are not mixed with clinical waste before treatment. However, since clinical waste is generated from many different activities within medical establishments, it is inevitable that chemical substances may find their way into the clinical waste stream, and some clinical waste may be contaminated with pharmaceuticals and chemicals. Moreover, it is improper and not practicable to open every package of clinical waste to inspect and confirm the absence of chemical substances. Therefore, treatment by autoclave or microwave technology would generate toxic emissions under such circumstances. In that respect, incineration has definite advantage by offering a fail-safe solution since chemicals present in the clinical waste stream can be completely destroyed by high-temperature incineration, hence there is less need for stringent waste segregation.
- 1.8** Other thermal treatment technologies such as pyrolysis and gasification have also been examined. These technologies are similar to incineration which makes use of the energy content of the waste to achieve thermal destruction, and would equally require an after-burner to completely destroy those fractions which have not been pyrolysed or gasified. Experience on the very few larger scale plants suggests that they require good control on the waste composition in order to provide suitable waste feed for pyrolysis or gasification and to reduce the formation of dioxins during these processes.
- 1.9** It is also noted that many European countries are restricting the landfill disposal of waste containing organic matter in accordance with the new EC Landfill Directive. The role of incineration will become more important as a well-proven technology for bulk waste reduction. Therefore, clinical waste, after treatment by these alternative technologies, may still have to be sent to the Waste to Energy Plants for co-incineration with municipal solid waste.
- 1.10** Based on the above review, while there are certain merits in adopting the emerging alternative treatment technologies, they cannot provide a total solution to deal with ALL kinds of clinical waste, apart from other constraints and unknown risk associated with these technologies. It is therefore recommended to adopt incineration as the treatment method for clinical waste, and the CWTC be modified at the earliest opportunity so as to provide a more environmentally sound disposal method.

INTRODUCTION AND BACKGROUND

Chapter 2

- 2.1** Clinical waste is generated in medical institutions such as hospitals, clinics, pathological and medical research laboratories. At present, the majority of clinical waste generated in Hong Kong is disposed of at landfills, while a small amount consisting of human tissues are incinerated at two Hospital Authority's incinerators or at the crematoria operated by the Food and Environmental Hygiene Department. Disposal of clinical waste by landfilling is not considered to be satisfactory.
- 2.2** In order to provide for proper disposal means for clinical waste in Hong Kong, the Government proposed to modify the Chemical Waste Treatment Centre (CWTC) to incinerate all kinds of clinical waste.
- 2.3** The Government presented the proposal to the LegCo Joint EA and Health Services Panel on 30 May and 24 Oct 1997, subject to the findings of an Environmental Impact Assessment (the EIA) on clinical waste disposal at the CWTC and public consultation. At the same time, the EPD also consulted the Kwai Tsing District Board (KTDB) on the proposal in early 1997.
- 2.4** Both the LegCo Panel Members and the KTDB members expressed concern on whether there would be any adverse environmental impact to the vicinity of the CWTC due to the implementation of the proposal.
- 2.5** The EIA was completed in March 1999 and the findings confirm that the CWTC is capable of treating both chemical waste and clinical waste in an environmentally acceptable manner. The Government then consulted the Advisory Council on the Environment (ACE) on the EIA on 3 May 1999. The ACE endorsed the findings and recommendations of the EIA study subject to some minor requirements. The Government committed to fulfill all ACE's requirements in implementing the proposed project.
- 2.6** The EIA study findings were consulted with the KTDB on 13 May 1999. The KTDB maintained their objection to the proposal of using CWTC to treat clinical waste.
- 2.7** The LegCo Joint EA and Health Services Panel was then consulted on the proposal to incinerate clinical waste at the CWTC and the EIA study findings on 14 Dec 1999 and 7 Jan 2000. The Government also invited an international expert to brief Panel members on the dioxin emissions in Hong Kong on 5 May 2000. In light of the concern raised by the Greenpeace and the Kwai Tsing District Council (KTDC) on the use of CWTC to dispose clinical waste at the Panel meetings, Panels members requested the Government to re-visit alternative clinical waste treatment technologies before a decision was made on the disposal arrangement for clinical waste in Hong Kong. The Panel Chairperson also requested the Administration to provide more information, in particular the emission levels and impact on the environment of such technologies, for further deliberations by the Joint

Panel.

- 2.8** To address the concerns of Panel members and the general public, the EPD has, in mid-2000, engaged an independent international expert on clinical waste management to review the currently available clinical waste treatment technologies and international practices of clinical waste treatment, and to identify the constraints of applying such technologies in Hong Kong. In addition, information has also been separately gathered by the professional staff of EPD on various clinical waste treatment technologies during their overseas technical visits or through other communication channels. This report summarises previous reviews of clinical waste treatment technologies carried out by the Government and Hospital Authority (HA), the findings of the expert's review, the information gathered by EPD, as well as other relevant information, and makes recommendations on the clinical waste disposal arrangements in Hong Kong.

PREVIOUS REVIEWS OF CLINICAL WASTE TREATMENT TECHNOLOGIES

Chapter 3

Review carried out by the Government

- 3.1** During the early stage of development of the clinical waste control strategy, the Government had reviewed the practices adopted by various countries in managing clinical waste (ERM Hong Kong [1994]. *Centralised Incineration Facility: International and Regional Comparative Assessment of Clinical Waste Management*. Final report.).
- 3.2** This report, completed in 1994, indicated that the clinical waste generated in Hong Kong was very similar to many other places and countries. Clinical waste was very heterogeneous in nature, comprising human tissues and amputated organs, soiled dressings contaminated with blood and other body fluids, sharps, infectious agents, microbiological cultures, containers contaminated with pharmaceuticals, chemicals, cytotoxic drugs and disinfectants, and infectious or contaminated animal carcasses and beddings arising from medical research etc. The report indicated that the preferred option for disposal of such heterogeneous nature of clinical waste was incineration in a number of countries and places (e.g. Germany, France, Italy, Spain, Singapore, Taiwan, Japan, Canada, UK and USA). Developing countries such as the Philippines, Indonesia and Thailand adopted co-disposal of clinical waste with municipal waste at the landfills. It was also noted that some alternative clinical waste treatment technologies were being developed in USA and in Germany. The practices adopted in the various countries and places are summarized in Appendix A.

Review carried out by the Hospital Authority

- 3.3** In mid-1998, the Hospital Authority (HA) arranged 4 key staff to attend a 5-day Medical Waste Treatment Technologies workshop organized by United States - Asia Environmental Partnership Environmental Exchange Program (USAEP EEP) and the United States Environmental Training Institute (USETI) in New York. The intention was to obtain first hand knowledge on the development and use of alternative clinical waste treatment technologies in USA.
- 3.4** Subsequently, the HA has commissioned a US consultant responsible for conducting the USAEP EEP workshop to examine the feasibility of using autoclave to treat clinical waste generated by HA's institutions, noting that on-site treatment might help reduce the overall expenditure on clinical waste collection and disposal (INSCITE [1999]. *Alternative Treatment Technology: Autoclaving for Clinical Waste. Conducted for the Hospital Authority, HK.*). The report prepared by the consultant indicated the following limitations of using autoclave:

- (a) most autoclaves do not handle recognizable anatomical wastes, even if shredders are used;
- (b) autoclaves do not handle chemotherapeutic or other toxic chemical and radiological wastes;
- (c) the amount of liquid clinical waste that can be processed is limited;
- (d) offensive odors can be generated;
- (e) volatile organic compounds (VOCs) may be emitted;
- (f) may require hospitals to change the method of waste segregation; and
- (g) heat recovery is generally not available.

3.5 The report indicated that autoclave is a proven technology for medical instrument disinfection and for pre-treatment of laboratory cultures before disposal. However, it does not provide a total solution for all types of clinical waste.

3.6 The pros and cons of other methods such as microwave, chemical treatment and pyrolysis have also been briefly compared with incineration. They are summarized in Appendix B.

3.7 The report also quoted an earlier study (Jones & Konheim, 1994) carried out to characterize and quantify the emissions from alternative technologies (Appendix L). The study concluded that:

- (a) carcinogenic compounds (e.g. formaldehyde and benzene) were emitted from the autoclave but not from incinerator;
- (b) the direct inhalation cancer risks were comparable for the incineration and autoclave alternatives if dispersion characteristics were similar;
- (c) the direct inhalation risk for autoclave emissions that were typically exhausted from a building vent with little or no plume rise was significantly greater than from the same size incinerator. Under some conditions, the cancer risk could exceed 10^{-5} ; and
- (d) all thermal treatment (e.g. autoclave and microwaves) should have the same regulatory attention as incinerators to ensure they pose low risk.

3.8 The consultant also examined the clinical waste management practices in HA's hospitals. It was found that the amount of clinical waste produced by HA's hospitals was the lowest of all the countries he had visited in the past 10 years. HA produced only 0.12 Kg/bed/day clinical waste in 1999, as compared to 5.5, 2.2 and 0.6 Kg/bed/day in UK, USA and the Netherlands respectively. It was noted that clinical waste segregation was consistently practised in all HA's facilities.

SUMMARY OF FINDINGS FROM THE EXPERT REVIEW

Chapter

4

- 4.1** To address the concerns of the LegCo Panel members and the general public, the EPD has, in mid-2000, engaged an independent international expert on clinical waste management, Mr. William K. Townend of the Torgam Development Ltd, to review the currently available clinical waste treatment technologies and international practices of clinical waste treatment, and to identify the scope of applying such technologies in Hong Kong. Mr. Townend was the immediate past President of the Institute of Waste Management (IWM) in the UK, as well as the Chairman of the Working Group on Health Care Waste of the International Solid Waste Association (ISWA). Mr. Townend has previously worked with the UK Environment Agency, and has extensive experience on clinical waste management. He has also acted as a consultant and adviser to the World Health Organization (WHO) and is the co-author of the WHO publication "Teacher's Guide: Management of Wastes from Health-care Activities". The review has also been assisted by Professor John D. Donaldson and Dr. Sue Grimes of the Centre of Environmental Research, Brunel University, UK. The Study Brief for the review and the Review Report are attached at Appendices C and D respectively. The key findings are summarized in the following paragraphs.
- 4.2** The review pointed out that clinical waste is potentially hazardous and aesthetically offensive. Clinical waste treatment serves the following important functions:
- (a) Disinfecting and/or sterilizing infectious materials in the clinical waste to reduce its microbiological hazard;
 - (b) Destroying the sharps in clinical waste to minimize its physical hazard (and to prevent reuse of disposable syringes in the underground market);
 - (c) Rendering clinical waste unrecognizable and un-offensive; and
 - (d) Achieving significant volume reduction.
- 4.3** Any clinical waste treatment technologies to be selected for use should be capable of fulfilling the above functions in an environmentally sound, safe and cost-effective manner. To achieve these, any treatment option should:
- (a) Possess automatic controls and built-in failsafe mechanisms;
 - (b) Have proper monitoring and recording systems;
 - (c) Possess system to ensure waste cannot bypass the treatment process; and
 - (d) Meet relevant occupational and safety standards.
- 4.4** The review identified that a wide range of technologies have been developed for treating clinical waste in the past few years. The expert described each technology in some details. He classified them into the more widely applied technologies (incineration, autoclaving, microwave and radio-wave treatment, chemical disinfection), other thermal treatment technologies such as pyrolysis and gasification, and novel technologies

(irradiation, plasma technology etc.). As pointed out by the expert, the novel technologies are emerging technologies and in general they have not been well proven commercially. For the more widely applied technologies, incineration has been the main disposal method for clinical waste for many years in many developed countries, even though alternative technologies such as autoclave, microwave treatment and chemical disinfection are gradually becoming more common in recent years.

4.5 The expert has made a detailed comparison of the more common clinical waste treatment technologies. A number of factors are considered to be particularly important in selecting the appropriate technologies:

4.5.1 Efficacy of Killing Infectious Microorganisms

4.5.1.1 One of the main purposes of clinical waste treatment is to disinfect or sterilize the waste to reduce the infectious biohazardous properties. The ability of a treatment technology to reduce the infectious materials is known as its efficacy. **Sterilization** means rendering the waste free of microorganisms. This cannot be absolute and difficult to prove. Hence, it is usually expressed as a probability of a number of microorganisms surviving a particular treatment process. This function is usually expressed as 6 log₁₀ reduction of survival probability in a microbial population, i.e. a 99.9999% reduction. **Disinfection** is difficult to define, as the effectiveness of individual disinfection process can vary. The guidelines of the Centres for Disease Control of US define the following levels of disinfection process:

- (a) *High-level disinfection* - can be expected to destroy all micro-organisms with the exception of large number of bacterial spores;
- (b) *Intermediate disinfection* - inactivates *Mycobacterium tuberculosis* vegetative bacteria, most viruses and most fungi; does not necessarily kill bacterial spores;
- (c) *Low-level disinfection* – can kill most bacteria, some viruses and some fungi; it cannot be relied on to kill resistant microorganisms such as the *M. tuberculosis* or bacterial spores.

4.5.1.2 Incineration is considered to be the most effective technology in **sterilizing** the waste because it burns the waste at high temperature to achieve complete destruction of all types of bacteria, viruses, fungi and other infectious agents. The resulting residue is a small amount of completely sterilized inorganic ash which can be disposed of at sanitary landfills.

4.5.1.3 The review indicated that the efficacies of alternative technologies (autoclave, microwave, chemical treatment) in disinfecting clinical waste depend on a number of operational factors and conditions. No national standards are yet available for assessing the efficacy of alternative technologies. The U.S. State and Territorial Association of Alternative Treatment Technologies (STAATT), which is a non-governmental association, is still in the process of developing standard procedures in evaluating the

efficacy of alternative treatment technologies, and suggested that alternative technologies should be subject to the recommended evaluation procedures prior to approval for use. It is also pointed out by the expert that the proper disinfection of clinical waste by these technologies is highly dependent on the skills of the waste disposal workers who determine the actual operating conditions during treatment of clinical waste, the nature of the waste, the packaging, whether the waste is shredded or not, the operating temperature and duration of treatment. It may be difficult to ensure complete destruction of all types of pathogens at all times. Hence, proper monitoring system to ascertain the disinfection efficacy must be implemented, e.g. to measure the killing of selected species of bacteria, viruses and fungi on a regular basis.

- 4.5.1.4** The review indicated that pyrolysis and gasification could also sterilize the clinical waste because they treated the waste at high temperature to achieve destruction of all types of microorganisms. Similar to incineration, the resulting residue is a very small amount of completely sterilized inorganic ash which can be disposed of at sanitary landfills. However, such technologies would require good control on the waste composition to provide suitable waste feed since those waste components which could not be pyrolyzed or gasified would require an after-burner to completely destroy these fractions. Therefore, these technologies have much similarity to incineration, and the clinical waste treatment plant operated by Zavin in the Netherlands is in reality a “pyrolytical” incinerator.
- 4.5.1.5** Regarding novel technologies such as radiation and plasma technology, the expert did not recommend the Hong Kong Government to experiment with such technologies since we need secure and reliable disposal arrangement.

4.5.2 Suitability for Removing Physical Sharpness and Obnoxious Appearance of Clinical Waste

- 4.5.2.1** This relates to the ability of the clinical waste treatment technologies in destroying sharps, rendering clinical waste unrecognizable and destroying residual amount of drugs and chemicals. Incineration is most versatile in this aspect as it can achieve complete destruction of all types of clinical waste and turns the waste into an ash-like substance. For alternative technologies, they are generally less effective in destroying sharps and rendering clinical waste unrecognizable unless they are equipped with powerful shredders.
- 4.5.2.2** Alternative technologies such as autoclave, microwave and chemical treatment are not recommended by many countries for treating human body tissues or amputated body parts. The said technologies cannot effectively disinfect such wastes without thorough shredding. Moreover, it is against cultural practice to shred these wastes (in many countries including Hong Kong), treat them with autoclave, chemical or microwave and then dispose of them with other municipal solid waste.

4.5.2.3 The review also indicated that several alternative technologies (e.g. autoclave, microwave, radio wave, chemical treatment etc.) may usually require shredding of clinical waste prior to treatment in order to ensure more even heating and effective penetration of steam or chemical into the interior of the waste. The shredder is always a problem since hard objects (such as contaminated metallic hip-joints and equipment which may be mixed with other clinical waste) may damage the blade of the shredder and hence require frequent equipment shutdown for repair and maintenance. The operator may be exposed to potential health risk when the shredder is opened which inevitably would expose the untreated clinical waste and the blade.

4.5.2.4 The inability of alternative technologies to treat all types of clinical waste means that clinical waste not suitable for these technologies must be segregated out for separate treatment, usually by incineration. The more stringent segregation requirement is generally not favored in the management of clinical waste because this means that the health care professionals have to spend more time and effort to separate the waste instead of caring for the patients. Additional segregation requirement may not be practically feasible in understaffed hospitals and sometimes simply not possible to do so, e.g. segregating residual chemicals and drugs from used syringes or other clinical wastes. Moreover, from the health and safety point of view, it is not practical and advisable to open the waste containers to check whether the waste has been properly segregated.

4.5.3 Air and Liquid Emissions

4.5.3.1 The review indicates that no clinical waste treatment technology is completely free from air and liquid emissions; some may generate more while some may generate less.

4.5.3.2 For incineration, the main concern is with air emissions such as dioxins and mercury. The health impacts of incineration have been well studied and recognized. However, if clinical waste incinerators are equipped with appropriate air pollution control equipment to meet the stringent air emission standards, incineration of clinical waste will not cause any adverse impacts on the environment and public health. The review indicates that incineration of clinical waste is still the main method of disposal of clinical waste in many European countries, Australia, Taiwan, Japan, Singapore, Malaysia and USA.

4.5.3.3 The review indicates that whilst dioxins would not be a problem for alternative technologies, other potentially harmful air emissions could be associated with alternative technologies. For example, autoclave facilities are known to emit wide arrays of toxic Volatile Organic Chemicals (VOCs). Clinical waste such as used syringes or used ampoules would contain small amounts of chemicals, pharmaceuticals and cytotoxic (anticancer) drugs. Swabs which are used to clean equipment and clinical utilities

may also contain residual amount of chemical disinfectants. Soiled dressings may also contain ointments and chemicals. Heat treatment at low temperature, e.g. steaming at 100°C, microwave treatment at 95-100°C, may not destroy the hundreds (if not thousands) types of such chemicals in the clinical waste. Moreover, new chemicals may be formed at elevated temperature. Mercury and mercury compounds, if present in the clinical waste, would also be evaporated from the waste during heating to 90-130°C.

4.5.3.4 In fact, there are very limited studies carried out to identify the nature of such emissions, and their potential environmental and health hazards are still unknown. The corresponding regulatory controls and research on the air emissions of these alternative technologies are apparently less well developed in various countries partly because of a lack of understanding of the emissions from these systems and partly due to the lack of public concern. These emissions would require control by appropriate air pollution abatement equipment similar to clinical waste incineration facilities. Nevertheless, detail guidelines or emission standards for the design of these facilities are not readily available due to the lack of research in this area.

4.5.3.5 Alternative technologies may also generate liquid emissions which have to be treated prior to discharge. The amount of liquid emissions may vary according to the technology used.

4.5.3.6 Pyrolysis and gasification of clinical waste may generate dioxins, and similar to incineration, would require proper air pollution control equipment to capture the dioxins and other toxic emissions.

4.5.4 Occupational Health Risks

4.5.4.1 The expert considered that the risk of incineration of clinical waste perceived by the public could be very significant, even though the actual risk of incineration at properly controlled facilities was very low. On the other hand, the expert has pointed out that certain occupational health risks, which was more real than the perceived risk of incineration, had already been reported for alternative clinical waste treatment technologies. For example, the USA National Institutes of Occupational Safety and Health reported a microwave leakage incident from a microwave treatment facility in 1997. The microwave which leaked into the working environment was found to be many times more than the health standards. In addition, the Centres for Disease Control (CDC) also reported that there was a recent outbreak of suspected occupational-related tuberculosis among employees at another alternative treatment facility (radio wave) in USA. Three employees acquired active tuberculosis; one of them was found to be multiple-drug resistant. One of the workers was infected with a strain of tuberculosis bacteria identical to the strain identified in a patient treated at a medical facility that sent waste to the medical waste treatment

facility.

4.5.4.2 The CDC report identified various problems ranging from microbiological aerosols, design problems, technical problems, work flow problems and fire hazard. The report points out that treatment of medical waste is not as simple as buying an equipment and pushing a button to operate. Instead, a comprehensive and environmentally sound and safe management system must be implemented to properly safeguard the health of the public and the waste-handling workers.

4.5.5 Subsequent Disposal of Treated Waste

The review indicates that clinical waste invariably contain residual amounts of chemicals, pharmaceuticals and cytotoxic drugs. Hence, even after autoclave, microwave or chemical treatment, the treated waste may still be contaminated with the wide arrays of residual amount of chemicals and toxic substances. For example, if the clinical waste contain mercury, the mercury can still be found in the treated clinical waste. Such treated waste should therefore be properly segregated, handled, transported and disposed (e.g. by incineration).

Recommendations

- 4.6** The constraints of applying the different clinical waste treatment technologies have been assessed by the expert with specific reference to the proposed Clinical Waste Control Scheme and due consideration of the local factors.
- 4.7** Based on the findings of the advantages and disadvantages, and the constraints on the use of alternative treatment technologies for HK, the expert recommended the Government to proceed with its proposed use of the Chemical Waste Treatment Centre to treat clinical waste.
- 4.8** In the longer term, the expert recommended the Government to:
- (a) keep abreast of the independent research being carried out worldwide and carry out a watching brief on the international standards for efficacy and environmental testing of various treatment technologies;
 - (b) keep abreast of developments in various alternative technologies, including novel treatment technologies; and
 - (c) after obtaining more information on a) and b), to consider installing at a suitable site an alternative treatment facility in the longer term.

INFORMATION COLLECTED FROM OTHER SOURCES

Chapter 5

5.1 Additional information on clinical waste treatment technologies have been obtained separately by the EPD. Several technical visits to overseas clinical waste treatment facilities have been made by EPD staff to understand the development of clinical waste disposal technologies. The purposes are:

- (a) to collect information from government officials in controlling or permitting different clinical waste treatment technologies in their own countries; and
- (b) to obtain first hand information through visits to different facilities and direct discussion with the facility operators.

5.2 A summary of information gathered on clinical waste disposal practices during such visits is attached at Appendix E. Information was also obtained from relevant authorities, organizations and suppliers through subsequent communications (Appendices F - J). In summary:

Incineration

- (a) High temperature incineration is still the most common method of clinical waste treatment in Europe (the Netherlands, Austria, France, and UK) and in the more developed countries or places in Asia (Japan, Singapore, Malaysia and Taiwan).
- (b) In these countries, one or more regional incinerators are usually built to treat clinical waste because individual hospital lacks the resource and expertise to properly build and operate the facilities.
- (c) Many incinerators are designed to co-incinerate hazardous waste with clinical waste. One of the reasons is that the treatment temperature and pollution abatement equipment are much the same for incinerating clinical waste and other hazardous waste.
- (d) All incineration facilities demonstrated compliance with local regulations on air emissions, which may vary from country to country. In particular, many European facilities are built to meet very stringent air emission requirements set out by the proposed European Commission (EC) Directives for Incineration.

Alternative Technologies

- (e) Alternative technologies (autoclave, microwave, chemical treatment) are also adopted in some of these countries (e.g. France, Australia, UK) but the number of facilities is far less in number than incineration.

- (f) Alternative technologies may still create emission problems other than dioxins (e.g. VOCs and odour) which attract less concern from the general public. However, such emission problems should be properly addressed through independent studies/research and by installing appropriate air pollution control equipment.
- (g) Alternative technologies are found more common in the U.S. In the U.S., autoclave and microwave treatment are getting more popular partly because of less objection from the local community (even though there may still be air emissions) and partly because of the high cost of retrofitting old incinerators. In some cases, even though the newly built incinerators can meet the most stringent air emission standards, the local community still objects to the operation of the facilities. It is noted that in several states, clinical waste after treatment by alternative technology is still incinerated in cement kiln as refuse-derived fuel. It should also be reckoned that these alternative technologies have yet to demonstrate their efficacies according to national standards which are still being developed.
- (h) In some European countries such as France, the clinical waste after “pre-treatment” by the alternative technologies such as microwave treatment, is co-incinerated with MSW at the Waste-to-Energy Incinerator. One waste management contractor in UK is also planning to do so when the EC Landfill Directive is implemented in the next few years.

Treatment Costs

- 5.3** When the LegCo Joint EA and Health Services Panel was consulted on the proposal to incinerate clinical waste at the CWTC and the EIA study findings, the estimated cost of disposal of clinical waste at the CWTC was raised. A revised capital cost of \$52 million for modification of the CWTC (see Appendix H) and an annual operating cost of \$22 million would be required for the disposal of 10 tonnes of clinical waste per day.
- 5.4** Most package plant suppliers claim that the capital and operating cost of alternative treatment technologies would be much cheaper than incineration. The EPD has collected more information on the costs of various treatment technologies (Appendices H to J). The capital cost of an autoclave is estimated to be higher than the CWTC option while the operating cost is expected to be lower than the CWTC option. Both the capital and operating costs of a microwave facility would be comparable with that of an autoclave facility.
- 5.5** The apparent lower capital cost estimates made by the suppliers usually cover the package plant only and do not include many other essential requirements for the entire clinical waste treatment facilities and operations in Hong Kong. They include:
- (a) Structures/buildings to house the autoclave/microwave/chemical plant, shredders and compactors;

- (b) Reception areas and associated structures for handling the vehicles delivering clinical waste to the facilities;
- (c) Facility to weigh the vehicles/clinical waste, and to calculate cost of treatment of each load of waste and the associated computer facilities to track the waste movement;
- (d) Facilities to automatically load transfer skips of clinical waste into the incineration or treatment facilities;
- (e) Cold storage facility for holding skips of animal and human tissue and amputated organs;
- (f) Washing facilities for washing and disinfecting all clinical waste transfer skips used by hospitals and clinics;
- (g) General facilities such as safety facility, ventilation and odour control facility, temporary storage facility for transfer skips used by hospitals, clinics and collectors;
- (h) General electrical and mechanical works; and
- (i) Cost to administer the project, opportunity land cost and contingencies etc.

5.6 The costs of providing such essential requirements and infrastructures are usually much more significant than the cost of a package treatment equipment.

5.7 In relation to the operating cost of alternative technologies, the UK NHS (Dept of Health) has pointed out in its technical memorandum that *"most manufacturers of alternative treatment technologies quote an operating cost for their product. These figures are formulated on inconsistent assumptions – for example, depreciation basis, interest rate, residual disposal etc. - and should not be used for selecting a technology."* The operating cost of alternative technologies quoted by some parties is purely direct cost of operating the equipment (e.g. electricity, water or chemical). It has usually been underestimated and should include but not limited to the following essential operations:

- (a) Provision of cleaning and disinfecting all transit skips (for safe transportation of clinical waste) before handing back to clinical waste collectors;
- (b) Repair and replacement of damaged transit skips;
- (c) Provision of back up clinical waste collection service in case of emergency;
- (d) Control and monitoring of air emissions and effluent discharges;
- (e) Carrying out of routine microbiological testings to ascertain satisfactory killing of designated species of microorganisms under operating conditions and certification by accredited laboratories;
- (f) Compilation of trip tickets, and preparation and submission of information to the Government on clinical waste received from all clinical waste collectors;
- (g) Provision of approved safety and environmental training for proper operation of the facility; and
- (h) Implementation of a sound Environmental Management System.

5.8 Experience in New Zealand indicated that operating cost of some autoclaving facilities was not cheaper than incineration of clinical waste (Appendix F). The World Bank's Guidance Note on Healthcare Waste

Management also indicated that radio wave treatment may be more expensive than incineration whilst the cost of autoclaving is very similar to that of incineration (Appendix K).

- 5.9** The cost comparison shown in the table in Appendix H summarizes the total capital cost and operating cost of incineration at CWTC and treatment at an autoclave facility. However, it should be noted that the table has not taken into account the cost required for consultant fees in site search, preliminary feasibility studies, environmental impact assessment, engineering feasibility study, site investigations, tender preparation etc. These costs would be considerable and need to be included in assessing alternative technology.

SUMMARY OF FINDINGS AND RECOMMENDATIONS

Chapter 6

- 6.1 The findings of the expert review and the information collected by EPD staff indicated that whilst alternative technologies have become more popular in USA and some countries, **incineration of clinical waste is still regarded as the main proven technology** in most European countries, Australia, Singapore, Taiwan, Malaysia and Japan. The concerns about dioxin, mercury and other air emissions have been satisfactorily addressed by installing appropriate pollution control equipment.
- 6.2 The rapid development of alternative and novel clinical waste treatment technologies in USA is due partly to the considerable cost of upgrading old hospital incinerators to meet the stringent air emission standards introduced in recent years and the need for expertise to operate the incinerators properly without violating air emission standards; while the main driving force is the public objection to build incinerators near their homes.
- 6.3 **The use of alternative technologies** (e.g. autoclave, microwave, chemical treatment), though may be less expensive in terms of both capital and operational costs, have limitations regarding the range of clinical waste which can be treated, as well as the lack of documented studies on their health and safety aspects. The present review and information collected during the technical visits indicate that these plants do produce discharges and air emissions, and proper pollution abatement systems should be installed. However, **there is no sufficient documented guideline and no emission standards supported by scientific researches or studies**. This is an important factor to be considered if they are installed in the hospital setting.
- 6.4 Waste segregation would help to reduce the amount of clinical waste requiring treatment, as well as to ensure that pharmaceuticals and chemicals are not mixed with clinical waste before treatment. However, since clinical waste is generated from many different activities within medical establishments, it is inevitable that chemical substances may find their way into the clinical waste stream, and some clinical waste may be contaminated with pharmaceuticals and chemicals. Moreover, it is improper and not practicable to open every package of clinical waste to inspect and confirm the absence of chemical substances. Therefore, **treatment by autoclave or microwave technology would generate toxic emissions** under such circumstances. In that respect, **incineration has definite advantage by offering a fail-safe solution** since chemicals present in the clinical waste stream can be completely destroyed by high-temperature incineration, hence there is less need for stringent waste segregation.

- 6.5** The use of alternative technologies always require shredding of clinical waste prior to treatment in order to ensure effective penetration of steam or chemicals into the clinical waste. However, there are unavoidable problems with the shredders which may pose potential health risk to the operators of the facility. The recent discovery of occupational-acquired tuberculosis in one of the alternative treatment facilities in USA also points to the **need to assemble more comprehensive information on the environmental, health and safety aspects of these technologies to quantify their risk.**
- 6.6** The review carried out by the expert indicated that some novel technologies (e.g. plasma-based technology) can also sterilize the clinical waste because they treat the waste at very high temperature to achieve destruction of all types of microorganisms. Similar to incineration, the resulting residue is a very small amount of completely sterilized inorganic ash which can be disposed of at sanitary landfills. However, such technologies are regarded as emerging advanced technologies and the expert did not recommend the HK Government to experiment with such technologies for the time being.
- 6.7** It is noted that the clinical waste after treatment with alternative technologies has been co-incinerated with municipal waste (MSW) at Waste-to-Energy facility rather than disposed at the landfills. Such practice would become more common in European countries when the new EC Landfill Directive is implemented, since these countries are moving away from landfills as a disposal method for MSW and rely on incineration to deal with non-recyclable combustible wastes.
- 6.8** In conclusion, while there are certain merits in adopting the emerging alternative treatment technologies, incineration has continued to play an increasingly important role in most European countries as the proven technology to treat clinical waste. The EIA findings have already concluded that the CWTC is fully equipped to treat clinical waste in full compliance with the stringent emission standards. **It is therefore recommended to adopt incineration as the treatment method for clinical waste, and the CWTC be modified at the earliest opportunity so as to provide a more environmentally sound disposal method.**

BIOHAZARD

REVIEW OF CLINICAL WASTE TREATMENT TECHNOLOGIES

CARRIED OUT FOR

ENVIRONMENTAL PROTECTION DEPARTMENT
THE HONG KONG SPECIAL ADMINISTRATIVE REGION GOVERNMENT



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CHAPTER 1 EXECUTIVE SUMMARY

1.1 All four of the objectives set out by The Government of the Hong Kong Special Administration Region in the Contract as follows are covered in the present review:

- a) To identify available clinical waste treatment technologies world-wide.
- b) To compare the pros and cons of the various clinical waste treatment technologies and where treatment technologies provide partial treatment or pre-treatment to advise on appropriate further treatment.
- c) To review the development and current situation of clinical waste disposal practices in countries overseas.
- d) To advise on the scope of applying various clinical waste treatment technologies to Hong Kong and the operational precautions if such technologies are adopted.

1.2 In this Executive Summary, the scope of study and the methodology used are outlined; and a précis of the results and advice are presented.

1.3 METHODOLOGY

1.3.1 Key data and information from the following sources have been obtained:

- The British Library
- The Internet
- Trade journals
- Published academic research
- Manufacturers' brochures
- Regulatory Organisations
- Non Governmental Organisations
- National and International Bodies

1.3.2 Detailed information on the practices involved in clinical waste management has been obtained from Europe, North America and the Far East. The efficacy testing criteria for the technology have been researched. The health and safety issues and environmental aspects of alternative technologies have been analysed.

1.4 SCOPE OF STUDY

The available clinical waste treatment technologies worldwide have been identified and researched. Most countries listed in the contract document have been covered and some countries not listed have also been included.

1.5 IDENTIFICATION OF DIFFERENT TECHNOLOGIES

1.5.1 The treatment technologies analysed from a process point of view are as follows:

- Incineration Treatment Technology
- Alternative Treatment Technology
- Novel Treatment Technology

Incineration Treatment Technology

1.5.2 This is now a well-established traditional practice, to which increasingly stringent emission and environmental control standards are applied. Modern plants, as in Hong Kong, can meet the current stringent environmental standards. Similar thermal treatment technologies (pyrolysis and gasification) have also been considered.

Alternative Treatment Technology

1.5.3 Established alternative treatment technologies, which fall under the generic heading Thermal Disinfection (excluding incineration) or Chemical Disinfection, have been dealt with. Four specific categories have been analysed:

- Wet thermal treatment (autoclaving)
- Dry thermal treatment (hot screw feed technology)
- Electromagnetic wave irradiation (microwave and radio-wave)
- Chemical disinfection

Novel Treatment Technology

1.5.4 Two new novel alternative treatments have also been considered:

- Plasma based systems
- Irradiation (by electron beam or radioisotopes)

1.6 COMPARISON OF DIFFERENT TECHNOLOGIES

1.6.1 The advantages and disadvantages, which are common to all three systems, are set out in full in Chapter 4 and 5 of the report.

- a) The main advantage of the alternative technologies is the lower capital cost of some of the package plants, and possibly operating costs when compared to incineration.
- b) There would also be less public resistance to the installation of the alternative technologies in other countries probably because they are smaller installations with less obvious air emissions.

1.6.2 The main point of concern is the fact that the efficacy of killing micro-organisms, environmental and safety standards and risk assessment for the alternative technologies are not yet fully developed and further independent research and testing are required.

1.6.3 One of the disadvantages of the alternative technologies identified is

the potential of releasing volatile organic compounds (VOCs), mercury and other un-characterized air emissions into the environment. Offensive odour may also be produced from autoclave. These can theoretically be minimised by installing appropriate air pollution control equipment. The air pollution control systems applied to incineration plants may be dissimilar to those applied to alternative technologies mainly because the waste is not being subjected to a combustion process in the alternative technologies. The control systems are likely to be simpler and less expensive but further research needs to be carried out to evaluate this issue.

1.6.4 Another limitation of the autoclave (and microwave, radio-wave, chemical treatment) system to treat human and animal tissue and body parts, pharmaceuticals, chemicals and cytotoxic drugs (which may be carcinogenic, mutagenic or teratogenic) are real at the present level of the development of the system and impose restrictions on the use of such system.

1.6.5 Grinding or shredding of clinical waste is necessary prior to treatment by various alternative technologies to ensure better penetration of the steam, chemical disinfectant, or proper heating in order to achieve better killing of micro-organisms. This is also necessary for removing physical hazards presented by sharps and to render all other types of clinical waste unrecognisable. However, the shredder is likely to be subject to mechanical failure or breakdown. If this occurs whilst it is charged with untreated clinical waste, considerable care must be paid to operator safety in the removal of the untreated waste and in the handling of the equipment (e.g replacement of damaged blades or removal of obstructions such as metal hips) which will have become contaminated. Furthermore, shredding of clinical waste may lead to the formation of microbial aerosols in the working place; this should be properly controlled to prevent occupational health risk.

1.6.6 Whilst incineration can destroy all micro-organisms and clinical waste, disinfection efficacy of various alternative technologies relies greatly upon operational conditions. A system must therefore be present for the alternative technologies to ensure achieving adequate disinfection because the treated, untreated or partially treated clinical wastes have similar appearance. Proper monitoring of the efficacy of disinfection of selected strains of bacteria, viruses and fungi must be carried out on a regular basis.

1.6.7 A moderate level of research and development work is being carried out on the novel treatment technologies. They may achieve complete destruction of micro-organisms and all types of clinical waste. Some tend to be more expensive both in capital and operating costs (than autoclave, microwave, and chemical treatment) and some more expensive than incineration. In most cases waste treated by irradiation can be disposed of by incineration at the Waste-to-Energy facility or properly designed landfill (obtaining where necessary the approval of the appropriate regulator), whereas waste treated by plasma technology could be directly landfilled.

1.7 PRACTICES IN OTHER COUNTRIES

1.7.1 A review of practices of using different clinical waste treatment technologies worldwide has been carried out. Whilst it has not been possible to obtain information from all of the countries listed in the contract, the information obtained from the countries where it has been possible and the additional ones gives a good representative sample of different sizes of population, geography, economic development and development of clinical waste management.

1.7.2 Three important observations have been noted:

- a) Incineration is still a very important and common disposal method particularly where landfill is limited and where there is the pressure to reduce biodegradable waste being disposed of in landfill sites as in the European Union. High temperature incineration is also still the most common method of clinical waste treatment in the more developed countries or places in Asia (Japan, Singapore, Malaysia and Taiwan).
- b) There is a wide divergence in the number of treatment and disposal systems both between countries and internally within countries (e.g. USA).
- c) There is an increasing use of the alternative technologies mainly due to cost consideration and public perception of the risks associated with incineration.

1.8 ADVICE ON THE APPLICATION OF VARIOUS CLINICAL WASTE TREATMENT TECHNOLOGIES IN HONG KONG

1.8.1 The constraints of applying the different treatment technologies have been assessed and researched with specific reference to the Hong Kong Government's proposed Clinical Waste Control Scheme and also giving due consideration to the local factors in Hong Kong.

1.8.2 The conclusions and the advice are set out in paragraph 7.4 and are based on the observations and findings contained in the present report.

1.8.3 Based on the findings of the advantages and disadvantages, and the constraints on the use of various alternative treatment technologies for Hong Kong, it would be more appropriate for the Government to proceed at once with its proposed use of the Chemical Waste Treatment Centre (CWTC) to incinerate clinical waste. Incineration is a well established and proven technology which produces the smallest amount of residues and such residues can be disposed of in a properly designed landfill site. There are also clearly established air emission standards for its regulation.

CHAPTER 2 BACKGROUND AND OBJECTIVES OF THE STUDY

2.1 BACKGROUND

2.1.1 The Government of the Hong Kong Special Administrative Region proposes to implement a Clinical Waste Control Scheme (CWCS) to provide legislative control over the collection, transportation and disposal of clinical waste in Hong Kong. The Government also proposes to modify the Chemical Waste Treatment Centre (CWTC) for the safe incineration of clinical waste. The reasons are as follows:

- a) The CWTC is equipped and designed to meet the most stringent air emission standards adopted by developed countries. It has sufficient capacity to handle all the clinical waste projected to arise over the next ten years.
- b) By modifying the CWTC, rather than building a new facility, significant resources and development time can be saved.
- c) Land can be saved, as there is no need to find another site for the incineration facility.
- d) Incineration offers a total solution to the treatment of different kinds of clinical waste without imposing stringent requirements on waste segregation.

2.1.2 To assess if it would be environmentally acceptable to dispose of clinical waste at the CWTC, an Environmental Impact Assessment was conducted in 1998. Various aspects were assessed, in particular the possible health risks due to emissions of dioxins and furans. The findings indicate that the maximum predicted concentration of such chemicals is equivalent to only 0.09% of the background concentration, and the calculated daily intake via inhalation is equivalent to 0.001% of the internationally accepted Tolerable Daily Intake standard of $1 \text{ pg TEQ kg}^{-1} \text{ d}^{-1}$. The results from a trial burn also indicated that emissions due to incineration of clinical waste would readily meet the proposed stringent emission standards, which are comparable to those adopted in other advanced countries. Overall, the results confirmed that the incineration of clinical waste together with chemical waste at the CWTC would not cause any adverse environmental impact.

2.1.3 The Hospital Authority also employed a consultant in early 1999 to carry out a preliminary study on the use of autoclaving to treat clinical waste; the study indicated that such alternative waste treatment technology might emit Volatile Organic Compounds and other toxic emissions to the atmosphere.

2.1.4 In December 1999 and January 2000, the Joint Panel on Environmental

Affairs and Health Services of the Legislative Council (LegCo) was consulted on the Government's proposal to modify the CWTC for the incineration of clinical waste. The HA report has also been submitted to the Joint Panel for information. The Greenpeace representatives at the meetings criticised the proposal. Greenpeace considered that the Government should adopt other safer and cheaper alternative clinical waste treatment technologies such as the use of autoclaves and microwaves, which they said, had been widely employed in the U.S. Their main concern with the incineration of clinical waste was the possibility of toxic air emissions, particularly dioxins and mercury.

2.1.5 In view of the objection and the claim that there was an increasing use of alternative technologies in some other countries, some LegCo Panel Members considered that the Government should review such alternative technologies before proceeding with the use of the CWTC facility to incinerate clinical waste in Hong Kong.

2.1.6 The Government is also concerned with various environmental and health risks associated with alternative technologies, noting that such risks have not been well documented in the literature.

2.2 THE OBJECTIVES

2.2.1 In the light of the concerns that have been identified, the Hong Kong Government has decided to engage an international expert on the subject to carry out a review of all available alternative clinical waste treatment technologies world-wide and to examine their advantages and disadvantages. The review will assist the Government to formulate their response if an individual hospital or a private company decides to establish one of these facilities for the treatment of clinical waste.

2.2.2 The international expert will carry out the following detailed tasks to achieve the overall objective of the study:

- a) Identify the clinical waste treatment technologies that are available world-wide.
- b) Compare the various alternative clinical waste treatment technologies and identify the advantages and disadvantages of each one. Where treatment technologies provide partial treatment or pre-treatment, advise on appropriate further treatment.
- c) Review the development and current situation with respect to clinical waste disposal practices in other countries.
- d) Give advice on the scope of applying various alternative clinical waste treatment technologies to Hong Kong, and the operational precautions that will be required if such technologies are adopted.

CHAPTER 3 THE SCOPE OF THE STUDY AND METHODOLOGY

3.1 GENERAL BACKGROUND

The social, economic and cultural background to the situation in Hong Kong and an appraisal of the work already carried out to implement a Clinical Waste Control Scheme will be studied first. This will be followed by an assessment of the report published by the Hong Kong Hospital Authority "Alternative Treatment Technology: Autoclaving for Clinical Waste".

3.2 DETAILED SCOPE OF THE STUDY

3.2.1 Research into and identify the available clinical waste treatment technologies worldwide by reviewing international literature and consulting the relevant agencies and organizations.

Obtain the necessary details so that an account may be given of the advantages and disadvantages of those clinical waste treatment technologies which have found wide application in overseas countries including, but not limited to, the following technologies: autoclaving, microwave treatment, chemical disinfecting systems.

The parameters to be compared shall include, but not be limited to, the following:

- Generation of toxic emissions and wastewater;
- Operational safety and health;
- Reliability and ease of maintenance;
- Volume reduction of waste;
- Handling of waste treatment residues;
- Waste treatment costs;
- Space requirements;
- Public perception; and
- Further treatment requirements prior to final disposal.

3.2.2 Carry out a review of the development of current clinical waste disposal practices in various countries. The countries and places reviewed shall include but be not limited to the following: U.S.A., Canada, UK, Germany, Australia, Japan, Taiwan and Singapore.

3.2.3 Identify if there is an increasing trend in the application of alternative technologies in overseas countries, particularly in the U.S., and the rationale behind such changes.

3.2.4 Assess and advise on the constraints of applying the clinical waste treatment technologies taking into account the following local factors in Hong

Kong:

- Nature and quantity of clinical waste;
- Clinical waste management practices;
- Environmental impacts;
- Health and safety aspects;
- Control and enforcement;
- Siting issues;
- Capital and operating costs;
- Availability of other existing and planned disposal facilities;
- Time of implementation etc. ;
- Government' s proposed Clinical Waste Control Scheme; and
- The study conducted by the Hong Kong Hospital Authority – “ Alternative Treatment Technology: Autoclaving for Clinical Waste” .

3.3 METHODOLOGY

3.3.1 Upon the commencement of the study, a visit was made to Hong Kong by the author of this report and there was an opportunity taken to visit a government clinic and a government hospital (Queen Mary Hospital) where the current practice of clinical waste management was examined on site. To fulfil the objectives of the study, the current situation with respect to alternative and novel technologies for the treatment of clinical waste has been analysed as follows:

- a) Available data and information on existing systems and their use have been researched using a variety of data sources including the British Library, The Internet, Trade Journals, Manufacturers Brochures, Professional Journals, International and National Regulatory Organisations, Non Governmental Organisations and published academic research.
- b) Information on the practices involved in clinical waste management has been obtained from countries in Europe, North America and the Far East.
- c) The available information on the efficacy testing criteria for the technology has been acquired.
- d) Available data obtained on the research that has been carried out on the health and safety issues associated with the alternative technologies.

3.3.2 The results of the research are detailed and discussed in Chapters 4, 5 and 6. In Chapter 7 advice is given on the scope of applying alternative technologies in Hong Kong. An Executive Summary of the study is given in Chapter 1.

CHAPTER 4. IDENTIFICATION OF DIFFERENT TECHNOLOGIES

4.1 INTRODUCTION

4.1.1 Since the beginning of the 20th century hospitals in a large number of countries have had access to on-site boiler plant and incinerators for the disposal of waste produced in healthcare. About 25 years ago a number of events combined to act as a catalyst for the changes that led to the development of the large-scale alternative technologies for the treatment of clinical waste. The events that led to entrepreneurial companies to take the opportunity of developing large-scale waste treatment plants based upon existing techniques of disinfection were:

- a) The greater awareness of the environment identified and promoted by the first United Nations Conference on the Environment held in Stockholm in 1972;
- b) The emergence of new global epidemics such as human immunodeficiency virus (HIV) and hepatitis B virus (HBV) creating fear and concern of the general public;
- c) Changes in waste management legislation and recognition of the risks associated with clinical waste
- d) Growth in the use of disposable articles, equipment and packaging used in healthcare activities and disposal by old incinerators;
- e) The introduction of legislation to achieve cleaner air emissions;
- f) The expense of providing new incineration plant and the expense of gas cleaning equipment for upgrading old incinerators;
- g) Public reaction to the siting of new incineration plants and old incinerators; and
- h) The resulting closure of a large number of hospital incineration plants due to lack of funding to retrofit these plants.

4.1.2 These events took place mainly in the United States of America and were triggered there to some extent by the changes in 1978, which led to the State waste management legislation in California as well as Clean Air legislation in the rest of the USA.

4.1.3 Definition of disinfection and sterilisation

One of the main functions of treating clinical waste is to minimize the biohazardous nature of the waste. It is necessary to define the terms "disinfection" and "sterilisation" before discussion of the different treatment technologies:

- a) **Sterilisation** means rendering free of micro-organisms. This can never be absolute but it should effect a reduction in the number of micro-organisms by a factor of more than 10^6 (i.e. more than 99.9999% are

killed).

- b) **Disinfection** is difficult to define, as the activity of a disinfection process can vary. The guidelines of the USA Centres for Disease Control (Garner & Favero, 1985) allow the following distinctions to be made: -

High-level disinfection: can be expected to destroy all micro-organisms with the exception of large numbers of bacterial spores.

Intermediate disinfection: inactivates *Mycobacterium tuberculosis* vegetative bacteria, most viruses, and most fungi; does not necessarily kill bacterial spores.

Low-level disinfection: can kill most bacteria, some viruses, and some fungi; it cannot be relied on to kill resistant micro-organisms such as tubercle bacilli or bacterial spores.

4.1.4 In this chapter, the alternative treatment (chemical, wet thermal and dry thermal, electromagnetic wave treatment), thermal (incineration, pyrolysis and gasification) and novel (plasma, irradiation) treatment technologies are described and the advantages and disadvantages of each technology identified.

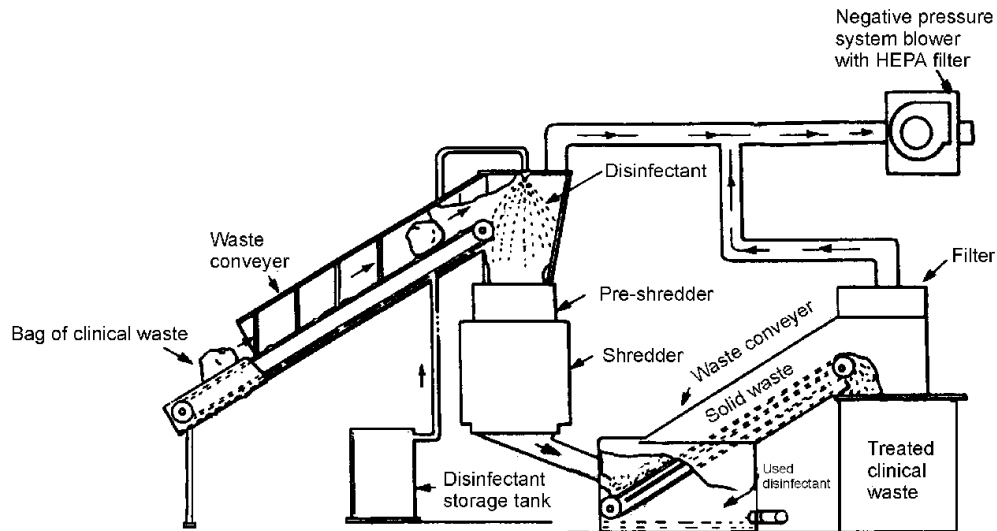
4.2. CHEMICAL DISINFECTION

4.2.1. Chemical disinfection is used in all clinical facilities on a routine basis to kill micro-organisms found on all types of surface particularly medical equipment, and the internal surfaces of buildings. Whilst chemical disinfection is commonly used to treat liquid waste (e.g. urine, blood etc), it has only been developed for the treatment of other clinical waste in the recent years.

4.2.2 The process involves the addition of powerful chemicals (disinfectants) to the waste to kill or inactivate the pathogens. Mechanical shredding of the waste is essential as a pre-treatment to ensure maximum contact of the chemical with the waste and to break up any voids due to packaging. Shredding is usually effected mechanically by the use of rotating blades. Water may also be added during the shredding process to cool the process and provide a medium for the chemical disinfection to take place. Chemicals in gaseous form can also be used for chemical disinfection; the agents used are ethylene oxide or formaldehyde (N.B. both are human carcinogens). This system is used mainly for the treatment of clinical items intended for reuse and which cannot be subjected to heat and moisture.

4.2.3 The waste is disinfected rather than sterilised. Some chemical disinfectants are specific in inactivating only certain types of micro-organisms whilst others can effectively kill all types. Knowledge of the types of micro-organisms present in the waste is therefore essential so that a proper chemical disinfectant can be used. Microbial resistance to different disinfectants has been well documented and it is possible to list the major groups of micro-organisms from most to least resistant as follows:

- bacterial spores
- mycobacteria
- parasites
- hydrophilic viruses
- viruses
- vegetative fungi and fungal spores
- vegetative bacteria



Schematic Diagram of a Chemical Disinfection System

4.2.4 The types of chemicals used for disinfection of clinical waste are mostly aldehydes, chlorine compounds (e.g. sodium hypochlorite or bleaching solution), ammonium salts and phenol compounds. The selection of the chemical disinfectant will depend upon:

- the technology to be employed
- the effectiveness of the chemical
- the risks to human health and the environment associated with the disinfectant
- the range of micro-organisms that are likely to be encountered in the process

4.2.5 There are two further methods of chemical disinfection that are in the development stage:

- a) The use of ozone for the disinfection of waste is at present under investigation. Ozone is a strong and relatively safe chemical.
- b) The second method is being developed by the Matrix Technology PTY of Australia. The waste is first pre-treated with peroxide and then undergoes shredding and alkaline oxidation by the addition of calcium

oxide (burnt lime) followed by encapsulation in a siliceous mass. The treated waste is then suitable for final disposal in a landfill site.

4.2.6 Advantages and Disadvantages of Chemical Disinfection System

The advantages are:

- a) The capital investment costs are generally lower than incineration.
- b) Depending upon the chemicals used and subject to the approval of the Regulators, the treated waste may be disposed of into landfill sites if the process has been properly carried out.

The disadvantages are:

- a) Shredding or milling of clinical waste is required prior to treatment with the chemical disinfectant. The shredder is likely to be subject to mechanical failure or breakdown. If this occurs whilst it is charged with untreated clinical waste, considerable care is required in the removal of the untreated waste should that be necessary and also in the handling of the equipment which will have become contaminated.
- b) Powerful disinfectants are required to kill the most resistant microorganisms. Such chemicals are also likely to be hazardous (e.g. glutaraldehyde and bleaching solution) and should be used only by well-trained and adequately protected personnel. For example, a worker was killed in a recent accident in HK due to the suspected inhalation of the commonly used bleaching solution during cleansing work (Apple Daily, 17 Aug 2000). Depending on the types of chemicals to be used, they may be irritating, corrosive, carcinogenic or generate unpleasant odour. Some may be explosive if not properly used. For example, the US National Institute for Occupational Safety and Health reported that ethylene oxide was involved in 10 explosions at industrial sterilization facilities between 1994 - 1998 and one of the explosions caused 1 death and 59 injuries (NIOSH, April 2000).
- c) Disinfection efficiency depends on operational conditions, e.g. it depends on the concentration of active ingredients and the degree of acidity or alkalinity. It is important to ensure that the chemical used will not be diluted in the treatment process beyond its effective concentration. Some disinfectants may be inactivated when mixed with blood or serum in the clinical waste. Some disinfectants cannot kill all bacteria spores, or with questionable virucidal action, or may be incompatible with some rubber or plastic in the clinical waste. A system must be present to ensure that adequate disinfection is achieved, as the treated, untreated or partially treated waste looks the same. Proper monitoring of the efficacy of disinfection of selected strains of bacteria, viruses and fungi must be carried out on a regular basis.
- d) Only the surface of solid waste will be disinfected. Hence, it is

important to ensure proper shredding of clinical waste to expose all surfaces to the chemicals. Any surface that is not exposed may still harbour pathogens.

- e) The system introduces an additional chemical burden on the environment and the most common chemicals that are used are chlorine based.
- f) Air and liquid emissions, which may be generated need to be properly controlled. For example, acidic components if present in the clinical waste may release chlorine from chlorine-based disinfectants (such as bleach). Chlorine gas is toxic and should be properly controlled.
- g) The system is unsuitable for:
 - i. cytotoxic drugs
 - ii. human and animal tissue and body parts
 - iii. pharmaceuticals
 - iv. chemicals
- h) The treated waste is likely to be wet. Care should therefore be taken to allow the waste to dry in a properly drained area before transport on road or delivery in a watertight vehicle/container so as to avoid spillage.

4.2.7 This system is only rarely used for the treatment of clinical waste due to the potential exposure of workers to the hazardous disinfectants. Treated materials can contain residual amounts of toxic chemicals that can be released over a period of time.

4.3 THERMAL DISINFECTION (WET, DRY AND ELECTROMAGNETIC WAVE TREATMENT)

4.3.1 Introduction

Thermal disinfection can be categorised as follows:

- a) Wet thermal treatment (Autoclaving)
- b) Dry thermal treatment (Hot screw feed technology)
- c) Electro magnetic wave treatment

4.3.2 Wet Thermal Treatment (Autoclaving)

Thermal disinfection using steam has been in use in healthcare facilities since the beginning of the 20th century as the principal method for sterilising reusable surgical and laboratory equipment. It has also been used for treating microbiological specimens before they are disposed as solid municipal waste. Autoclaving or steam sterilisation systems use superheated steam to sterilise the waste in metal pressure vessel of sufficient strength to withstand the required pressures and in a controlled manner. They are designed to allow the waste to be in direct contact with the steam for sufficient time at the required temperature and under the necessary pressure so that the pathogenic micro-

organisms present in the waste are killed. There are four main phases in the complete autoclave cycle:

a) Phase 1 - Introduction of steam

The saturated steam can be introduced into the autoclave vessel in two ways. They are: -

- by air displacement and the use of gravity where the cold air sinks to the bottom of the vessel being replaced by the saturated steam,
- a vacuum is created in the vessel by exhausting the air present prior to the addition of the steam.

b) Phase 2 - Temperature raising

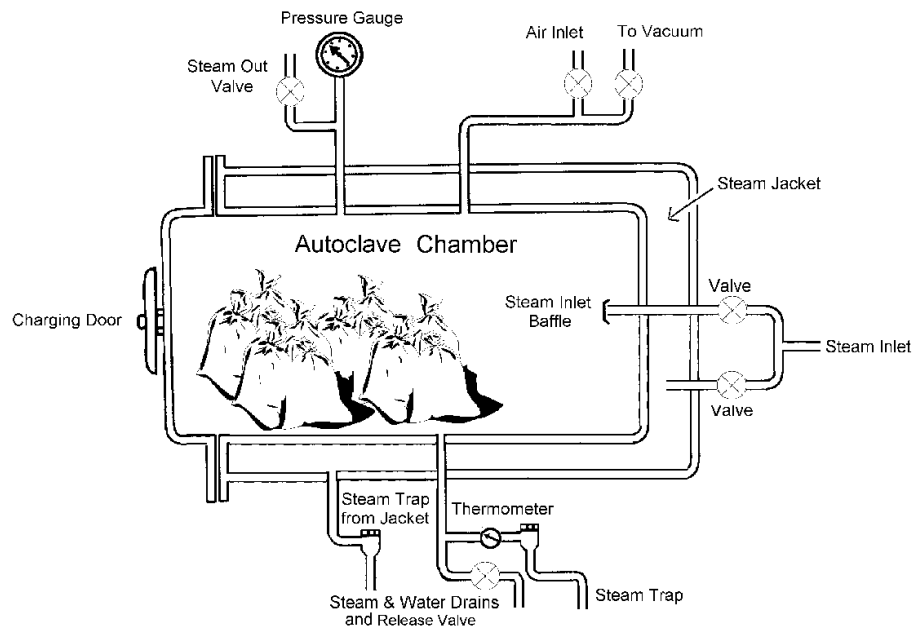
As the steam is added the pressure and temperature increase until such time as the requirements for a successful operation have been met.

c) Phase 3 - Exposure

The waste in the autoclave is then held in the vessel and exposed to these conditions until such time as the waste has been disinfected.

d) Phase 4 - Cooling

This is a cooling down period when the steam is slowly exhausted from the vessel and the pressure returns to that of one atmosphere.



Schematic Diagram of An Autoclave (With No Shredder)

Autoclaving is conceptually simple and has been proven over many years in the healthcare sector. Its development and use for waste management is of more recent origin. It has become accepted as a suitable system for the treatment of clinical waste in the USA and is more commonly employed than other alternative technologies. Its use is increasing world-wide both as a pre-treatment system prior to final disposal in the municipal Waste-to-Energy plants and for disposal in highly controlled situations in landfill sites. There is a

wide variety of manufacturers and of systems in operation and the manufacturers are usually prepared to design a system to meet the particular needs of the customer.

The systems can be divided into the following categories:

- a) Small table-top Autoclaves
These are normally used in laboratories or operations having small quantities of clinical waste to dispose of such as the surgeries and the clinics of doctors, dentists or veterinary surgeons. They will produce the steam required within the system by adding water and will treat one charge only before adding more water. They are usually between 60 and 200 litres in size.
- b) Laboratory Autoclaves
They are floor standing and can be connected to the hospital steam lines. They are used in laboratories for the disinfection of laboratory waste prior to its leaving the laboratory for either further treatment by shredding or for final disposal.
- c) On-site Autoclave Treatment Plants
They are free-standing devices that can be sited outdoors in specifically designed and specified areas. They are fully insulated and will either be connected to the steam lines within the hospital or have their own dedicated steam boiler and pump if a pre-vacuum system is used.
- d) Large Scale Wet Thermal Treatment Systems
These facilities are usually designed to treat the waste from more than one hospital and can either be operated by a group of hospitals or by a commercial operator. They can be either sited on land belonging to one of the hospitals or a site belonging to the merchant operator depending upon the circumstances.

There are a variety of ways in which these systems can be designed:

- a) Simple steam disinfection of the containerised waste without any pre-treatment or post-treatment and the containers of treated waste are transported for final disposal at landfill sites or at Waste-to-Energy plants.
- b) Pre-treatment of the waste by shredding after which the waste is placed in the treatment vessel. After treatment the waste is bagged and then ready to be taken for final disposal as in (a).
- c) Disinfection of the containers of waste in the autoclave followed by shredding and compaction prior to final disposal as in (a).
- d) Bags of clinical are placed into a pressure vessel with a separate rotating internal drum. High-pressure steam is then added causing the containers of waste to become soft and during agitation in the rotating

drum the bags will disintegrate. The disinfected waste is then subjected to a vacuum condensing system to dry the waste, which is then passed through a size reduction system (e.g. a shredder) before being delivery for final disposal as in (a) above.

- e) The wet thermal treatment system can also be combined with a chemical treatment system. For example, one patented system is designed to sterilise, render unrecognisable and make reusable all forms of clinical waste (except pathological and pharmaceutical waste). This is achieved by first subjecting the waste to shredding and pulverisation with the simultaneous introduction of sodium hypochlorite (bleach). This is claimed to sanitise both the equipment and the waste. The system then separates excess fluids from the waste using an auger press for re-circulation. The last stage of the process has an encapsulated auger where steam is injected onto the waste in temperature-controlled conditions. It is claimed that the residual waste is sterilised and has nearly dry constituency. It can then be sent for recycling as it is no longer infectious and falls out of the category of for example the European Union definition of hazardous waste or to final disposal. The sterile waste can then be passed through a patented recycling system where the waste is fed into a rotating gravity separator where water is again added to float the lighter material from the heavy fraction which fall to the bottom of the system. The lighter fraction will flow to a de-watering centrifuge. The treated waste is then classified by being passed over jets of air - the heavier particles drop to the floor of a chamber and the lighter particles pass into another chamber. The plastic waste after this process is polypropylene and polyethylene and can be used to produce waste containers such as sharp's containers and other products such as fence posts etc. The sale of the recycled plastic waste will depend on regional market requirements. Recycling of plastic clinical waste will normally only be considered if a business case has been made to justify the investment in the patent recycling system. For example, if there is already supply of cheaper raw or recycled plastic materials (e.g. in Hong Kong), it may not be economically viable to recycle the plastic from clinical waste.

There are many factors which affect the process of autoclaving and hence the efficacy of disinfection:

- a) Presence of residual air within the autoclave chamber prevents effective sterilization by reducing the temperature of the steam regardless of the pressure. This may lead to inadequate sterilization of clinical waste. Some autoclaves overcome this problem by using vacuum to pull all residual air from the chamber and to burst the bags containing the clinical waste. Alternatively, the bags should be shredded. However, this will lead to the formation of microbial aerosols which may be released to the outside of the chamber (Marshall et al, 1999). Proper microbiological filter must be present to minimize the microbial hazard. However, few commercial units are equipped with H.E.P.A. (High Efficiency Particulate Air) filters on their vacuum exhaust systems to

address this issue. The third way is to require the waste facility workers to open the bags, but this is not recommended because this will place the worker at risk due to microbial aerosol in the bags.

- b) Factors that can cause incomplete displacement of air include: improper loading (which may prevent the circulation of steam within the chamber) and the accidental use of heat resistant plastic bags.
- c) Waste such as large body parts, large quantities of animal bedding and fluids inhibit direct steam penetration and may lead to inadequate sterilization under standard conditions.

4.3.3 Advantages and Disadvantages of Wet Thermal Treatment Systems

The advantages are:

- a) The capital investment costs are lower than incineration.
- b) The treated waste, if the process has been properly carried out, may be disposed of into landfill sites or to Waste-to-Energy plants subject to the approval of the Regulators.
- c) Hospital staff is familiar with operations of small-scale autoclave and steam sterilisation systems.

The disadvantages are:

- a) Clinical waste may require shredding prior to treatment to ensure better penetration of steam into the waste. The shredder is likely to be subject to mechanical failure or breakdown. If this occurs whilst it is charged with untreated clinical waste, considerable care is required in the removal of the untreated waste should that be necessary and also in the handling of the equipment which will have become contaminated.
- b) Autoclaving heats the clinical waste to 121°C-131°C. Vapour will be formed during this heating process. Chemicals such as residual amount of pharmaceuticals, disinfectants and cytotoxic drugs unavoidably associated with clinical wastes would be vaporised and escape into the environment. Mercury, if present in the clinical waste, would also be vaporised at this temperature due to its high volatility. There is also a possibility of the production of offensive odours. Hence, air emissions may need to be properly controlled. Autoclaving also makes the waste wet; liquid emissions may be formed and need to be controlled.
- c) Disinfection efficiency depends on operational conditions, e.g. residual air in the chamber may reduce efficacy of killing pathogens, cold spots may be present if waste is too closely packed or the chamber overloaded, steam may not be able to penetrate if the bags of clinical waste are tied too tight etc. A system must be present to ensure achieving adequate disinfection, as the treated, untreated or partially treated

waste looks the same. Proper monitoring of the efficacy of disinfection of selected strains of bacteria, viruses and fungi must be carried out on a regular basis.

- d) There will be with certain systems an additional chemical burden on the environment. The most common chemicals that are used are chlorine based.
- e) The system is unsuitable for:
 - i. human and animal tissue and body parts
 - ii. pharmaceuticals
 - iii. chemicals
 - iv. cytotoxic drugs
- f) The treated waste is likely to be wet. Care should therefore be taken to allow the waste to dry in a properly drained area before transport on road or delivery in a watertight container/vehicle so as to avoid spillage.
- g) To treat the waste with steam above 100°C would require treatment under high pressure. Special safety precautions are required and requirements may have to be complied with under the Boiler and Pressure Vessel Ordinance in Hong Kong. Dry hypochlorides or any other strong oxidizing material must not be autoclaved with organic materials such as paper, cloth etc (i.e. oxidizer + organic material + heat may produce an explosion) (California State Polytechnic University, 1995).

4.3.4 Dry Thermal Treatment (Screw-feed Technology)

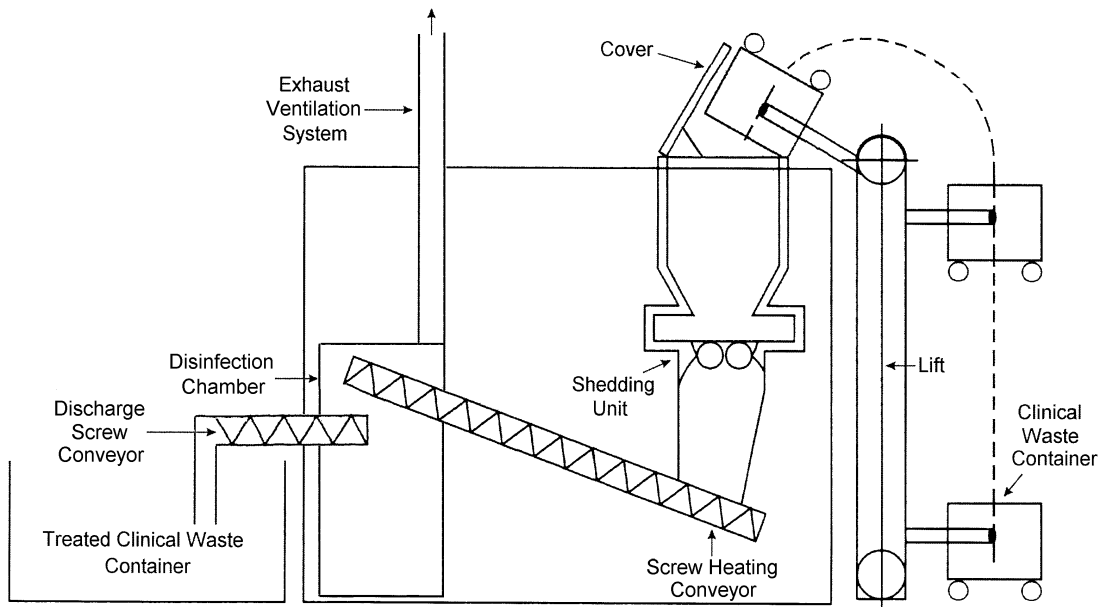
One type of the dry thermal disinfection processes is based upon screw-feed technology where the waste is first shredded and then heated by a rotating auger. Patented systems based upon continuous feed augers are already operating in a number of applications. The system requires the waste to be shredded to a particle size of about 25mm. The waste then enters the auger, which is pre-heated to a temperature of 110°C-140 °C by oil circulating through its central shaft. The waste is then propelled through the auger during a 20-minute retention time. There is no direct contact between the hot oil and the clinical waste. The waste residues are then compacted for final disposal to landfill sites or Waste-to-Energy plants.

4.3.5 Advantages and Disadvantages of Dry Thermal Treatment Systems

The advantages are:

- a) The capital investment costs and possibly the running costs are lower than incineration.
- b) The treated waste, if the process has been properly carried out, may be disposed of into landfill sites or to Waste-to-Energy plants subject to the approval of the Regulators.

- c) The treatment process does not involve the use of hazardous chemicals.



Schematic Diagram of a Dry Thermal Disinfection System

The disadvantages are:

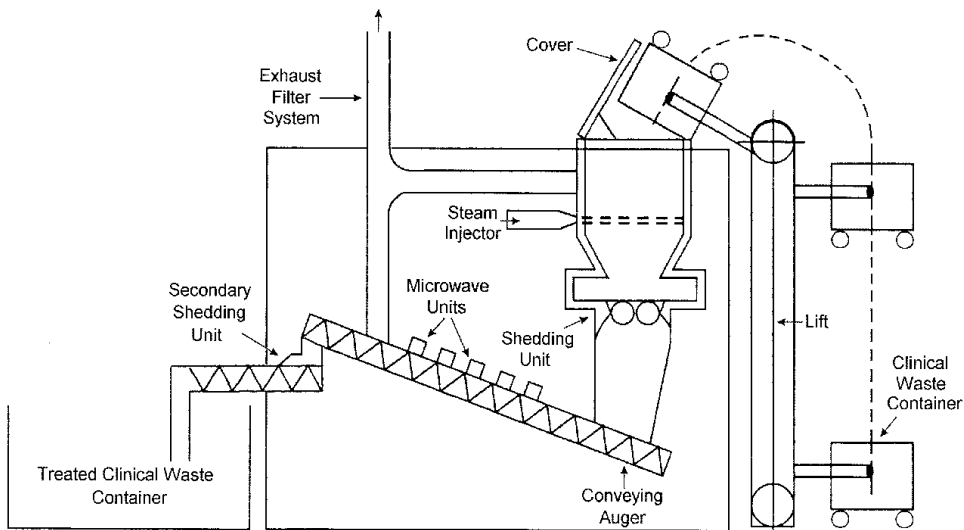
- a) Shredding or milling of clinical waste is necessary prior to treatment. The shredder is likely to be subject to mechanical failure or breakdown. If this occurs whilst it is charged with untreated clinical waste, considerable care is required in the removal of the untreated waste should that be necessary and also in the handling of the equipment which will have become contaminated.
- b) Disinfection efficiency depends on operational conditions. A system must be present to ensure achieving adequate disinfection, as the treated, untreated or partially treated waste looks the same. Proper monitoring of the efficacy of disinfection of selected strains of bacteria, viruses and fungi must be carried out on a regular basis.
- c) Dry thermal treatment heats the clinical waste to 100°-131°C. Vapour will be formed during this heating process. Chemicals such as residual amount of pharmaceuticals, disinfectants and cytotoxic drugs unavoidably associated with clinical wastes would be vaporised and escape into the environment. Mercury, if present in the clinical waste, would also be vaporised at this temperature due to its high volatility. There is also a possibility of production of offensive odours. Hence, air emissions may need to be properly controlled.
- d) The system is unsuitable for:
 - i. human and animal tissue and recognisable body parts
 - ii. pharmaceuticals

- iii. chemicals
- iv. cytotoxic drugs

4.3.6 Electromagnetic Wave (Microwave and Radio wave) Disinfection Systems

Microwaves are short, high frequency electromagnetic waves which are generated in electron tubes, with built-in resonators, special oscillators or solid-state devices to control the frequency. Most micro-organisms are destroyed by the action of microwaves at a frequency of about 2450 MHz and a wavelength of 12.24 cm. Microwave thermal treatment systems for clinical waste operate by agitating the water molecules in or on the surface of the waste materials causing them to vibrate and the vibration produces heat. In a microwave treatment unit a loading device transfers the wastes into a shredder, where it is reduced to small pieces. Steam is then added to the waste, which is then transferred to the irradiation chamber. The chamber is equipped with a series of microwave generators. The waste is then irradiated for about 20 minutes. The microwaves heat the moisture contained within the wastes to the point (usually about 95°C) that the clinical waste contained therein is disinfected. Once irradiated, the waste is then compacted inside a container for final disposal to either a landfill site or a municipal Waste-to-Energy plant.

The efficacy of microwave disinfection should be checked routinely by microbiological tests. The microwave process is used in several countries (e.g. USA) and is becoming increasingly popular. However, relatively high costs coupled with potential operation and maintenance problems mean that it is not yet recommended for use in developing countries (WHO, 1999a). Microwave irradiation equipment with a capacity of 250 kg/hour (600 tonnes/year, assume operating at 8 hr/day x 300 days/year), including loading device, shredder, steam humidification tank, irradiation chamber, and microwave generators, plus a waste compactor, may cost about US\$ 0.5 million.



Schematic Diagram of a Microwave Disinfection System

A proprietary system of treatment in use in the USA is known as the Electro-thermal Deactivation (ETD) process. The system includes a system of pre-grinding the waste and then passes the waste through a field of high-intensity low-frequency radio waves oscillating at a frequency of 10 mega-hertz to heat the waste. It is claimed that the pathogens in the waste are killed at atmospheric pressure and at temperatures as low as 90°C and that they can penetrate deeper than higher frequency waves like microwaves.

4.3.7 Advantages and Disadvantages of Electromagnetic Wave Disinfection Systems

The advantages are:

- a) The capital investment costs and possibly the running costs are lower than incineration.
- b) If the process has been properly carried out, the treated waste may be disposed of into landfill sites or to Waste-to-Energy incinerators subject to the approval of the Regulators.
- c) The treatment process does not involve the use of hazardous chemicals.

The disadvantages are:

- a) Exposure to electromagnetic wave radiation is dangerous especially when high energy or high intensity of radiations involved. It is known that microwave radiation can heat body tissue the same way it heats other materials. The lens of the eye is particularly sensitive and exposure to high levels of microwaves can cause cataracts. Likewise, the testes are very sensitive to changes in temperature. Accidental exposure to microwave can cause sterility. It can also cause burns, and damages to the nervous system. There is also a possibility of danger from long-term exposure to low-level microwaves. A continuous electromagnetic wave leakage monitoring system and programme must therefore be implemented.
- b) Shredding or milling of clinical waste is necessary prior to treatment to ensure better penetration of steam into the waste. The shredder is likely to be subject to mechanical failure or breakdown. If this occurs whilst it is charged with untreated clinical waste, considerable care is required in the removal of the untreated waste and also in the handling of the equipment which will have become contaminated.
- c) Disinfection efficiency depends on operational conditions. A system must be present to ensure achieving adequate disinfection before disposal as the treated, untreated or partially treated waste looks the same. Proper monitoring of the efficacy of disinfection of selected strains of bacteria, viruses and fungi must be carried out on a regular basis.

- d) Electromagnetic wave treatment, like autoclave treatment, heats the clinical waste but to 95°C-100°C only. Vapour will still be formed during this heating process. Chemicals such as residual amount of pharmaceuticals, disinfectants and cytotoxic drugs unavoidably associated with clinical wastes would be vaporised and escape into the environment. There is also a possibility of offensive odours. Hence, air emissions may need to be properly controlled. Microwave treatment also requires the waste to be wet and this may need to be supplemented with a steam supply. Liquid emissions may be formed and need to be controlled, despite the amount of liquid may be less than that of autoclave treatment.
- e) Relatively high costs coupled with potential operation and maintenance problems mean that the system is not yet recommended for use in developing countries (WHO, 1999a).
- f) It has been reported that the efficiency of the microwave system will decrease if the liquid content exceeds 10%, if the metal content of the waste is greater than 1% or if metal pieces larger than 0.2 kg are present (Brunner, 1996).
- g) The system is unsuitable for:
 - i. pharmaceuticals
 - ii. human and animal tissue and body parts
 - iii. chemicals
 - iv. cytotoxic drugs

4.4 THERMAL TREATMENT (INCINERATION AND PYROLYSIS/GASIFICATION)

Incineration

4.4.1 Incineration is the traditional method of treating clinical waste. The technology has been developed for over a century and the environmental impacts on the environment have been extensively studied. Improvements in incineration technology and pollution abatement equipment can minimize the environmental impact of incineration of clinical waste. Modern state-of-the-art clinical waste incinerators can meet the most stringent environmental standards.

Pyrolysis

4.4.2 Pyrolysis is the process of chemical decomposition of organic materials by heat (up to 2500°C) in the absence of oxygen. This process is commonly used in the manufacture of charcoal or coke for many years. Pyrolysis results in a gas stream containing primarily hydrogen, methane, carbon monoxide, carbon dioxide, and various other gases and volatile organic compounds and inert ash, depending on the characteristics of the material being pyrolyzed. These gases are then incinerated in a secondary chamber at a very high temperature. Metals and ceramics are not reduced in size but are disinfected by the very

high temperature of the treatment unit. All residues are collected in a receptacle and emptied as needed. An air-cleaning unit is still required to remove unacceptable air pollutants, such as dioxins and heavy metals, from the effluent gas stream. This system can be applied to clinical waste. An example is the plant in the Netherlands at Dordrecht operated by Zavin.

Gasification

4.4.3 Gasification is a process similar to pyrolysis but where the materials to be treated have a high carbon content and are heated to temperatures as high as 1300°C with limited amounts of oxygen. Energy rich gases are produced. These gases are then incinerated in a secondary chamber at a very high temperature. The waste materials are decomposed and sterilised in the process and the gases that are produced are treated by passing a series of scrubbers and filters to remove the pollutants (e.g. dioxins, furans etc.) and either are burnt to produce energy or used to pre heat the waste.

4.4.4 Advantages and Disadvantages of Incineration and Pyrolysis/ Gasification

The advantages are:

- a) They can significantly reduce the volume and weight of clinical waste;
- b) They can destroy all infectious micro-organisms most effectively;
- c) They burn all types of clinical waste to ash and make them unrecognisable;
- d) Shredding of clinical waste is not required;
- e) They can completely destroy residual amounts of cytotoxic drugs, pharmaceuticals and toxic chemicals in the clinical waste and hence does not require stringent segregation of clinical waste for separate treatment;
- f) They do not produce VOCs since the latter will be burnt out during incineration;
- g) Heat recovery is possible; and
- h) The environmental impacts have been extensively investigated and made known so that proper abatements can be carried out.

The disadvantages are:

- a) Incineration of PVC-containing clinical waste may produce air emission with dioxins and furans if proper air pollution control equipment is not installed;
- b) Incineration of clinical waste contaminated with mercury and other heavy metals may produce air emissions with such heavy metals if proper air pollution control equipment is not installed;
- c) Capital cost may be higher than some other alternative technologies; and
- d) There is considerable public concern and objection due to the perceived risk even though pollution abatement equipment can effectively remove air pollutants.

4.5 **NOVEL TREATMENT TECHNOLOGIES**

4.5.1 In this section two novel technologies (Plasma-based system and irradiation) for treating clinical waste are described and the advantages and disadvantages are identified.

Plasma Based Systems

4.5.2 Dr. Irving Langmuir, an American chemist and physicist, first applied the word "plasma" to ionised gas in 1929. Plasma consists of a collection of free-moving electrons and ions from atoms that have lost electrons. Energy is needed to strip electrons from atoms to make plasma. The energy can be of various origins: thermal, electrical, or light (ultraviolet light or intense visible light from a laser). With insufficient sustaining power, plasmas recombine into neutral gas. Plasma can be accelerated and steered by electric and magnetic fields, which allows it to be controlled and applied. It also provides many practical uses.

High-temperature plasmas in arc furnaces can convert, in principle, any combination of materials to a vitrified or glassy substance with separation of molten metal. Substantial recycling is made possible with such furnaces and the highly stable, non-leaching, vitrified material can be used in landfills with essentially no environmental impact. The temperatures reached in a plasma arc furnace are considerably more than that required to disinfect the waste. For example the plasma torch process uses an electric arc to attain temperatures as high as 10,000°C to destroy waste. One of the major disadvantages of this novel technology is its extremely high capital and operating cost. Some plasma systems claim that there is no emission problem. However, an earlier USEPA report "Retech, Inc., Plasma Centrifugal Furnace – Applications Analysis Report" indicated that there were emissions from the plasma treatment process (USEPA, 1992). The particulate emission exceeded the Resource Conservation Recovery Act (RCRA) limits and the report concluded that a more efficient air scrubbing system was required. High NO_x concentration in the stack gas was also noted.

Irradiation

4.5.3 A treatment system has been developed based on electron beams, which have the ability to destroy micro-organisms and sterilise a wide variety of materials. The electron beam generator is similar to those used for cancer therapy equipment in the hospitals and for sterilisation of foods and pharmaceuticals in the industry. Electrons from the beam interact with the electrons in the molecular structure of the target material, depositing energy and breaking the chemical bonds of organic compounds and fragmenting micro-organisms. While a material is being irradiated, it is never in contact with any radioactive materials, and the electrons used to treat the clinical waste would not make it radioactive.

Other systems may make use of ionising radiation from radioisotopes to treat clinical waste. All types of irradiation systems require extensive shielding to

protect the workers.

4.5.4 Advantages and Disadvantages of the Novel Technologies

The advantages are:

- a) Provided that the process has been properly carried out, the waste treated by irradiation may be disposed of into landfill sites or Waste-to-Energy plants subject to the approval of the Regulators.
- b) Novel technologies such as plasma-based systems can significantly reduce the volume and weight of clinical waste. Similar to incineration, plasma-based systems can kill all micro-organisms, make clinical waste unrecognisable, can completely destroy residual amounts of cytotoxic drugs, pharmaceuticals and toxic chemicals in the clinical waste and hence does not require stringent segregation of clinical waste for separate treatment, and can destroy VOCs.

The disadvantages are:

- a) There is insufficient information to assess the cost due to the fact that there are very few plants in use for the treatment of clinical waste but the capital investment costs and operational costs are likely to be about the same as or higher than incineration. One of the major disadvantages of irradiation system is its extremely high capital and operating costs.
- b) Where the ionising radiation comes from radioisotopes there is the problem of disposing of any radioactive waste created during the process.
- c) The biggest disadvantage of novel technologies is that they are most likely to be marketed as novel techniques by small entrepreneurial companies specially designed for the customer and therefore limited proven track record is available from the prototypes. This will certainly mean that they will be constantly modified whilst in operation. Experience in this area has meant that the facility is either out of use for periods of time or in some cases has failed completely. Selecting novel prototype technologies particularly where it will be the only facility in Hong Kong is not something to be considered lightly as clinical waste is in constant production and very reliable facilities must be provided for its treatment and disposal.
- d) Shredding or milling may be necessary prior to treatment by irradiation. The shredder is likely to be subject to mechanical failure or breakdown. If this occurs whilst it is charged with untreated clinical waste considerable care is required in the removal of the untreated waste should that be necessary and also in the handling of the equipment which will have become contaminated.
- e) Disinfection efficiency in the case of irradiation will depend upon operational conditions.

- f) Irradiation cannot destroy the residual amounts of cytotoxic drugs, pharmaceuticals and toxic chemicals in the clinical waste.
- g) Air and liquid emissions, which may be generated, need to be properly controlled.

4.6 SUMMARY

4.6.1 The advantages and disadvantages of the various alternative and novel treatment technologies have been identified in this chapter. They have been summarised in Table D of Chapter 5.

4.6.2 In brief, clinical waste treatment technologies should be able to:

- a) Adequately disinfect or sterilize infectious materials in the clinical waste to reduce its microbiological hazard so that no further special treatment is required for subsequent disposal;
- b) Destroy the sharps in clinical waste to minimize its physical hazard (and more importantly to prevent reuse/recycling of disposable syringes in the underground market);
- c) Render clinical waste un-recognizable and un-offensive; and
- d) Achieve significant volume reduction.

4.6.3 Any clinical waste treatment technologies to be selected for use should be capable of fulfilling the above functions in an environmentally sound, safe and cost-effective manner. To achieve these, the treatment system should:

- a) Possess automatic controls and built-in failsafe mechanisms;
- b) Have proper monitoring and recording systems;
- c) Possess system to ensure waste cannot bypass the treatment process; and
- d) Prevent creating other occupational and safety problems in the first place.

4.6.4 The alternative technologies have the following advantages:

- a) The capital investment costs and possibly the running costs are lower than incineration;
- b) If the process has been properly carried out, the treated waste may be disposed of into landfill sites or to Waste-to-Energy incinerators subject to the approval of the Regulators;

- c) They do not produce dioxins and furans; and
- d) They attract less public concern.

4.6.5 It should be noted that alternative technologies (autoclave, microwave and chemical treatment) have the following limitations:

- a) They are not able to significantly reduce the volume and weight of clinical waste;
- b) They may not be able to destroy all infectious micro-organisms at all times and the process of disinfection or sterilization depends greatly on the skills of the operators;
- c) They cannot make clinical waste unrecognisable, unless they are equipped with shredders or grinders which are not only problematic but also create airborne pathogen hazard to the operators of the treatment facility and maintenance staff (WHO, 1999a);
- d) They cannot destroy residual amounts of cytotoxic drugs, pharmaceuticals and toxic chemicals present in the clinical waste and hence require more stringent segregation of clinical waste to allow for separate treatment (WHO, 1999a; Table B);
- e) They may require addition of chemical disinfectants which may be hazardous to human and other living things;
- f) They generate toxic and carcinogenic VOCs and other toxic heavy metals in the vapour during the heating process. The VOCs and toxic heavy metals cannot be destroyed at low temperature. Some may also generate bad odour. All these may create occupational and safety hazards and must be properly controlled;
- g) Heat recovery is not possible; and
- h) Environmental impacts have not been extensively investigated or made known.

CHAPTER 5 COMPARISON OF DIFFERENT TECHNOLOGIES

This chapter compares the different technologies for treating clinical waste from the following aspects:

- Costs and financial implications
- Health, safety and environmental impacts
- Efficacies
- Reliability and ease of maintenance
- Handling of residues and further treatment requirements prior to final disposal
- Space requirements
- Public perception of risk

5.1 **COSTS AND FINANCIAL IMPLICATIONS**

5.1.1 The "polluter pays principle" should be applied when dealing with waste produced at healthcare facilities and all of the costs be applied to the function including segregation, storage, collection, purchase of equipment and labour costs as well as the treatment and disposal costs.

5.1.2 In the WHO publication "Safe Management of Wastes from Clinical Activities", an example was given for the disposal costs per tonne of different technologies in Switzerland. In general, the cost of incineration with high standards of treatment and pollution control is comparable to wet thermal disinfection while that of chemical disinfection is about half. The capital costs of providing a new alternative technology facility are generally less than that for a new incineration plant. However the operational costs are comparable for a wet disinfection system.

5.1.3 However, when assessing the costs of purchasing and operating a new treatment plant various points need to be taken into account and an annual average disposal cost arrived at (Table A). It should be noted that:

- a) The cost quoted by a supplier of a treatment facility usually only includes the cost of the package equipment rather than all the costs as shown in Table A.
- b) For some alternative and novel technologies, the life cycle cost may not be known as some of them are only newly developed.
- c) A number of factors affect the total costs of disposal of clinical waste particularly where all of the waste types cannot be dealt with in the same facility and some waste has to be separately collected and disposed of by incineration. For example, pharmaceutical, cytotoxic and chemical wastes, and body parts cannot be destroyed by alternative treatment technologies (WHO 1998) (Table B).

Hence, careful assessment of the total costs should always be made.

TABLE A Cost Evaluation

CAPITAL COSTS	Site costs	Land purchase, Infrastructure, Utilities
	Consultancy Fees	Environmental Assessment, Engineering, Architectural design.
	Construction Costs	Building, Storage, Offices, Treatment Plant.
	Finance	Interest, Taxes, Accountancy Fees.
OPERATION COSTS	Finance	Interest, Taxes, Accountancy Fees.
	Pre-processing	Compaction, Containers, On site transport, Human resources, Chemicals, Training, Maintenance, Protective clothing.
	Off- Site Transport	Vehicles, Weighing, Maintenance, Human Resources, Protective clothing, Disposal Costs.
	Processing costs	Human resources, Utilities, Electricity, Water, Repairs and Maintenance, Consumables e.g. filters and chemicals, Training, Regulator compliance, Disposal of waste products and wastewater.
	Administration costs	Records, Insurance, Licences.

Source of information: Torgam Developments.

TABLE B Treatment of Various Types of Clinical Waste by Various Methods

Systems	Infectious Waste	Anatomic Waste	Sharps	Pharmaceutical Waste	Cytotoxic Waste	Chemical Waste
Two-chamber, rotary kiln (CWTC Incinerator)	Yes	Yes	Yes	Yes	Yes	Yes
Single chamber incinerator	Yes	Yes	Yes	No	No	No
Pyrolytical incinerator	Yes	Yes	Yes	Small amount only	No (yes for modern ones)	Small amount only
Chemical disinfection	Yes	No	Yes	No	No	No
Wet thermal treatment	Yes	No	Yes	No	No	No
Microwave irradiation	Yes	No	Yes	No	No	No
Sanitary landfill	Yes	No	No	Small quantities	No	No

Based upon: WHO Teachers Guide (1998)

5.2 **HEALTH, SAFETY AND ENVIRONMENTAL IMPACTS**

5.2.1 Emissions from incineration and the potential impacts on the health and environment have been extensively studied (US EPA, 1991). On the other hand, whilst there was a rapid development of non-burnt alternative technologies to treat clinical waste in other countries, e.g. USA, there was a lack of proper attention to the potential health and safety impacts of such technologies.

5.2.2 A preliminary study carried out by Cole et al. (1993) for USEPA indicated that there were emissions of microorganisms from specific points in the microwave and mechanical/ chemical units. The study suggested that any technology which allowed access to the chamber during the shredding and grinding of untreated clinical waste, or where a phase of operation in the treatment process remained open to the environment would have the greatest potential of generating microbial aerosols. Microbial aerosols will invariably be generated if clinical waste is shredded or ground before treatment. Very good control must be in place to prevent escape of the aerosols from the shredder into the surrounding environment.

5.2.3 In November 1997, a Report was published by the USA National Institutes of Occupational Safety and Health (NIOSH) -"Control of Aerosol (Biological and Non-biological) and Chemical Exposures and Safety Hazards in Medical Waste Treatment Facilities" in which it is stated that " *Concern for medical waste treatment workers came from the unique character of the waste material and varying treatment technologies. Medical waste contains numerous chemicals that are themselves hazardous to worker health, and the Medical Waste Treatment technologies have the potential to generate others.*" The NIOSH Report also pointed out that little work had been carried out to assess the emissions from the alternative technology facilities apart from a study carried out for the USEPA on biological emissions conducted by Research Triangle Institute (Cole et al, 1993). Before this work there had been no research carried out specifically on the identification and assessment of hazardous exposures to the workers in the clinical waste alternative technology facilities.

5.2.4 The NIOSH report studied in detail four different technologies at four different sites:

- a) Off-site steam autoclave
- b) Off-site microwave
- c) On-site prototype pyrolysis plant
- d) Off-site mechanical/chemical treatment facility

and showed that the workers at clinical waste treatment facilities using alternative technologies are subjected on a daily basis to many types of health and safety hazards:

- a) blood borne pathogens (e.g. AIDS, hepatitis B virus etc.)
- b) other infectious agents
- c) exposure to hazardous drugs, chemicals and aerosols
- d) non-ionising radioactivity (microwave etc.)
- e) noise (arising from shredding and compacting etc.)

- f) heat stress
- g) ergonomics
- h) wounds from handling sharps and medical instruments

and exposure could be by the following routes:

- a) skin
- b) mucous membranes
- c) inhalation
- d) ingestion

5.2.5 Safety hazards and risks of injury were identified as:

- a) lifting
- b) moving
- c) slips
- d) falls
- e) machine guarding
- f) electrical problems

5.2.6 The safety hazards which are faced by workers on-site such as:

- a) wet floors
- b) untidy working conditions
- c) hazards from electrical equipment
- d) obstructions
- e) ergonomic considerations
- f) protective clothing - it's design and application
- g) worker's hygiene
- h) blood splashing

are identified in the report and are very similar to those found in industrial or hospital situations everywhere.

5.2.7 The three main areas of concern where information was not readily available were also identified as:

- The emission of volatile organic compounds (VOCs)
- Gaseous and particulate emissions
- The hazards from irradiation

Risk due to Toxic Volatile Organic Compounds in Air Emission

5.2.8 It is stated in the NIOSH Report that "*Volatile organic compounds are expected to be components of medical waste and may be formed and emitted during the treatment processes.*" Emissions of gaseous and particulate contaminants from medical waste treatment technologies have not been well characterised. Thus, data were not available for selecting target chemicals to be monitored at the waste facilities.

5.2.9 The report indicated that there were a wide range of VOCs found in the facilities and only 29 VOCs which exceeded 0.05 mg/m³ were reported. In the Summary of the Report, it stated that "*several VOCs were observed in each facility (i.e. the autoclave, microwave, chemical treatment and pyrolytic*

facilities), but no Occupational Safety and Health Administration (OSHA) Permitted Exposure Levels (PEL's) or American Conference of Governmental and Industrial Hygienists (ACGIH) Threshold Limit Values (TLV's) were exceeded". Results showed that whilst VOC concentration of individual chemical was acceptable within the facilities, the findings did highlight the total VOC concentrations could be high (e.g. 3 – 3.5 mg/m³ in the autoclave facility and 1.5 – 6.5 mg/m³ in the microwave facility). The findings also highlighted the variety of compounds that can be found in clinical waste and day-to-day variations in composition. For example, the formaldehyde concentration of an autoclave facility was found to be in the range of 0.08 - 0.18 mg, as compared to the ACGIH TLV of 0.37mg/m³ (ceiling limit) and the OSHO PEL of 0.94 mg/m³. Since all of the tests were carried out inside the building where the facility was located, it is not known what the levels were outside the building.

5.2.10 However, the exposure limits quoted are for single chemicals only. The health effect of a mixture is a more complex issue and it can be entirely different from those of individual components. In some cases, the individual chemical may act on the same organ or tissue or by similar toxicological mechanisms and their effects are 'additive'. In other cases, the overall effect is much greater than the sum of the individual effects and the effects are 'synergistic'. There are also 'potentiation' cases when one component has an effect but the second component does not but enhance the effect of the former one in a mixed exposure (American Conference of Industrial Hygienists, 1998; UK Health & Safety Executive, 1999; HK Labour Department, 1998).

Risk of Infection due to Micro-organisms in Aerosols

5.2.11 The risk of infection in using alternative and novel technologies is not well understood. The 1997 NIOSH report indicated that the risk of infection is difficult to estimate even when using very good data for exposure and documented seroconversion rates. Neither good exposure data nor documented seroconversion rates for clinical waste treatment workers were available. For this analysis, seroconversion rates for healthcare workers were used to represent the rate for clinical waste treatment workers. This was recognised to be an overestimate because most infectious organisms die off outside the ideal conditions of a host and the farther removed in time the organism is from contact with the host the lower the chance for causing infection. For waste, the temperature, humidity, and nutrient conditions are not optimal, so viability and, hence, infectivity will decline with time. Therefore, because clinical waste workers are not exposed to infectious agents immediately after they leave the host, clinical waste treatment facility workers are expected to have a lower seroconversion rate than healthcare workers. However, the NIOSH Report highlighted that:

- a) The risk of infection not only extends to the workers themselves, but to their family and close associates outside the workplace.
- b) This risk of disease transmission may be through the occupational acquisition of infection by the workers and the transmission of disease through normal modes to their families and friends.
- c) This transmission may occur because the worker may take home

- infectious agents on his clothes if personal protective equipment and clothing are not provided or not used as recommended.
- d) This had happened in other occupations.
 - e) Increased caution is required if any of the secondary exposure involves immuno-compromised individuals (children, elderly, or HIV-infected).

Irradiation Hazards

5.2.12 The NIOSH report indicated that there was an incident involving a leakage of microwave close to the shredder of one of the microwave units. The levels much exceeded $10\text{mW}/\text{cm}^2$ (the maximum limit set by the Occupational Safety & Health Association) and pegged the survey meter off-scale. Two microwave meters were used on site; however, both of them were out of calibration and one of them had lead batteries. The leak was readily reduced once the operator was told of the situation. The microwave radiation exposure would be controlled by regular maintenance with operating equipment. This finding points out that, in addition to regular checks of the treatment equipment, all testing equipment must be regularly checked, calibrated as needed, and maintained. Failing that, the operators may not easily notice the leakage from the microwave system until mishaps occur.

Other Hazards and Incidents

5.2.13 Further to the publication of the NIOSH report in 1997, there was a recent outbreak of suspected occupational-related tuberculosis (TB) among employees at a clinical waste treatment facility in USA (NIOSH, 1998). Three employees acquired active TB. It was shown that each of the 3 patients had a different drug susceptibility pattern, thus eliminating person-to-person transmission between these 3 employees. One of the cases was infected with a strain of tuberculosis bacteria (Mtb) identical to the strain identified in a person treated at a facility that sent waste to the clinical waste treatment facility. Furthermore, one of them was found to be multiple-drug resistant.

5.2.14 A detail evaluation of health hazard of an alternative treatment facility was conducted by the NIOSH of the Centres for Disease Control (CDC). The facility started operating in 1992 and was permitted to treat sharps, infectious waste and small amounts of human tissues using radio frequency wave (RF). The following waste types were not accepted: chemotherapeutic waste, chemicals and radioactive waste. The facility consisted of 13,500 square feet area. Approximately 2300 lb/hr (i.e. about 1000 kg/hr) of clinical waste was treated.

5.2.15 The alternative treatment facility used a primary shredder to shred the waste to 4-8" diameter and a secondary shredder to less than 3/8" diameter in a containment room. The shredded waste was then compacted to a density of 25 pounds per cubic foot in a press room. Water was sprayed onto the shredded waste to ensure 10 to 15% moisture. The shredding and compacting processes were carried out in an enclosed area which was under negative pressure. Exhaust air was filtered by a series of filter to ensure sterility when discharged

to the surrounding environment. The moistened waste was then heat-treated at 95°C using RF.

5.2.16 CDC identified several factors in the alternative treatment facility that could result in employee exposures to aerosolised bacteria (including Mtb) and other bloodborne pathogens (e.g. hepatitis B, hepatitis C, human immunodeficiency virus etc):

- a) Shredding and compacting of infectious waste created the potential for aerosolization of the products contained in the waste prior to heat treatment;
- b) Deficiencies in the design of the process which resulted in the clogging of the process line, and a ventilation system which was unable to ensure that the in-feed chute (for feeding clinical waste to the treatment facility) would remain under negative pressure when such clogs occurred. When clog occurred, a situation called “blowback” frequently occurred, i.e. the air from the containment room would blow back out of the in-feed chute.
- c) Direct contact of the workers with the waste (including exposures to needles, sharps, blood, human tissues etc.) during repair and maintenance of the equipment such as shredders;
- d) Exhaust air from the RF treatment unit was originally exhausted outdoors. However, due to odour complaints from the local community, the company had to change the process to recirculate the odorous exhaust air from the treatment unit back into the containment room.
- e) The process required all the employees to use airline respirators working in the containment room. The inadequacy of the respirators was noted since NIOSH investigators still detected odour in the containment area while using the company-supplied airline respirators.

5.2.17 The CDC also identified potential fire hazard of the alternative treatment facility. They noted that after prolonged use, carbon would accumulate on the surface of the RF oven (“cooking vessel”). They observed that a vessel actually “arc’ and caught fire while being removed by a fork-lift.

5.2.18 The CDC further noted that the process required homogeneous treatment of waste at 95°C for a fixed period of time to ensure inactivation of infectious micro-organisms. However, they observed that the temperature probing techniques employed would not accurately measure the temperature and that the employees informed the NIOSH that waste not reaching 95°C was occasionally disposed of without being re-processed.

5.2.19 A draft WHO publication (WHO, 1999c) reported that 13 other workers also showed evidence of being exposed to tuberculosis in the RF facility but were not symptomatic. It also reported that tuberculosis has not been reported at other USA plants where sealed containers of clinical wastes were processed directly without opening and/recycling the containers.

5.2.20 On 4 Oct 2000, the CDC further reported the use of advanced molecular biotechnology to identify the DNA fingerprints of the Mtb bacteria and confirmed that processing clinical waste in the alternative clinical waste treatment facility resulted in the transmission of Mtb to at least 1 facility worker (Johnson et. al. , 2000).

Discussion

5.2.21 Sufficient independent work has not been carried out on all of the alternative technologies such that all the inherent problems have been identified with certainty. This is particularly the case with respect to the emissions both within the building containing the systems or externally, and the effects on the health and safety of the workers or the general public. The scientists who have carried out the work in this field have called for the additional study to be carried out. There is also a need for comprehensive operator training, preventive maintenance systems and regular inspections to prevent, for example, the leakage that occurred around one of the microwave units and other environmental and safety hazards mentioned above.

5.3 EFFICACY

5.3.1 The introduction of the alternative technologies for the treatment of clinical waste caused concern amongst the environmental and public health agencies in a number of States in the USA. As a result, the representatives of about 15 States in the USA organised a series of meetings between 1992 and 1994 to discuss the issues and arrived at a set of standard approaches to the regulation of the alternative clinical waste treatment systems. One of the main concerns is the efficacy of the technologies to kill the wide range of micro-organisms in a complicated matrix in the clinical waste. Questions were also asked about the effects of the new systems on the occupational health and safety of workers, the environment and the effects on the general public. The technical and administrative procedures for permitting and reviewing the new technologies were the principal aims of this group as well as the formulation of a set of standards. In 1994 the group became known as the State and Territorial Association on Alternative Treatment Technologies (STAATT). The first official document produced by the organisation was published in 1994 and was the Technical Assistance Manual State Regulatory Oversight of Medical Waste Treatment Technologies.

5.3.2 This guidance document describes the consensus of the participants on the following topics:

- a) Recommendations as to the levels of microbial inactivation for use in the evaluation of treatment systems;
- b) Establishment of specific pathogen surrogates for efficacy testing of technologies;
- c) Development of enumeration formulae for the quantification of efficacy test results;
- d) Defining specific evaluation procedures for generators:
 - i. Commercial facilities

- ii. Healthcare facilities
- iii. Research and development facilities
- iv. Private practitioner facilities
- f) Devising specific criteria and requirements for:
 - i. Waste residue disposal
 - ii. Operator training
 - iii. Challenge loads
- g) Development of testing protocols for:
 - i. State permitting/licensing of treatment systems
 - ii. Site permitting
 - iii. User verification and challenge testing by different types of use

5.3.3 Since its publication, this guidance document has become widely accepted as the standard reference document on the subject in the USA and in a number of other countries. One particular standard defines the levels of microbial inactivation required for clinical waste treatment (See Table C). The minimum requirement for alternative treatment technologies recommended by STAATT is Level III. The various alternative treatment technologies should be able to achieve Level III provided that the equipment is operated properly.

TABLE C STAATT Standard for Microbiological 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 <i>B. stearothermophilus</i> or <i>B. subtilis</i> spores at a 4 log ₁₀ reduction or greater.
Level IV	Inactivation of vegetative bacteria, fungi, lipophilic/hydrophilic viruses, parasites and mycobacteria and <i>B. stearothermophilus</i> spores at a 6 log ₁₀ reduction or greater.

5.3.4 Since the publication of the STAATT document in 1994, new technologies have been introduced to the clinical waste market. These were addressed in the 1998 meeting of the STAATT and the existing recommendations were revised to take account of the recent technological advances. The revised edition (STAATT II) is due to be published in the near future.

5.3.5 However, up to the moment, there are no national standards for all the countries studied in this report. For example, even in USA where the treatment of clinical waste by alternative technologies has been debated for over ten years, a national standard for clinical waste treatment has yet to be realised.

5.3.6 A private company, the Underwriters Laboratories, Inc. in USA (UL), after consulting with representatives of the STAATT which has developed the guidance document for evaluating alternative technologies, is preparing a draft Standard (UL2334) with a view to seeking recognition of this Standard as an American National Standard through the Accredited Organisation Method of the American National Standards Institute. A Technical Committee has been set up to address various issues of emerging technologies. The Committee has established 7 Working Groups to assist in organising and developing various requirements. These Groups are as follows:

- a) Efficacy Work Group
- b) Equipment / Facility Protection Work Group
- c) Input / Output Work Group
- d) Maintenance Work Group
- e) Regulatory Acceptance Work Group
- f) Worker Safety Work Group
- g) Production Control Work Group

5.3.7 The Standard is intended to determine whether individual equipment or system provides for sufficient microbial inactivation and reduction of the risk of injury to persons and damage to property incident to their use. To date, the Standards Development Technical Committee has met five times in 1999 and 2000. However the Standard is still in the draft stage.

5.3.8 Furthermore, the UK Environment Agency and Scotland EPA are still considering recommendations from consultants on whether the operation of clinical waste treatment facilities in the UK should achieve the Level III criteria and that in certain situations, [e.g. from hospital wards with known pathogens such as multiple drug-resistant *Staphylococcus aureus*] waste should be treated in accordance with Level IV (UK NHS, 1998). This may be particularly relevant to the HK situation as it has been reported that *Staphylococcus aureus* resistant to most known antibiotics in the world has already been isolated in hospitals in HK (SCMP, 1999).

5.3.9 In respect of thermal treatment systems for disinfection of clinical waste, the UK Environment Agency and Scotland EPA are also still considering whether it is appropriate to specify a minimum temperature to ensure adequate killing of the micro-organisms (UK NHS, 1998).

5.3.10 The STAATT II meeting also reckoned that operation of alternative technologies require mandated operator training because the efficacy of treatment and safety will depend on the operator skills. The proposed "ASME Standard for the Qualification and Certification of Medical Waste Incinerator Operators (Sept 1992)" has been reviewed for its potential applicability as a guideline for developing required elements for operator training. The guideline has yet to be prepared and approved by the relevant authorities.

Discussion

5.3.11 The criteria for efficacy testing for the alternative clinical waste treatment technologies have taken ten years to develop and this has been an

iterative process, which will continue until all of the problems which have been identified are overcome. This issue applies to all of the alternative and novel technologies where disinfection of the waste is the main objective and there is a need to demonstrate that the treated waste is disinfected to an acceptable scientifically based standard.

5.4 RELIABILITY AND EASE OF MAINTENANCE

5.4.1 Autoclave has been used by hospitals for many years for sterilizing surgical equipments and laboratory cultures. There should be less maintenance problem of the equipment itself. However, shredders may pose considerable operational and maintenance problems as metallic and other hard objects may lead to blockage and damage of the shredders. Independent information on the reliability of other alternative technologies and their ease of maintenance is not readily available and this is one area that requires further study. This is particularly true for the novel treatment technologies.

5.4.2 On the other hand, incineration has a long history. In 1877, the first municipal waste incinerator in the world was opened in Manchester England following earlier trials of the system in Nottingham. High pressure steam was first generated from waste in Lancashire in September 1899; this ultimately led local councils to generate electricity to power trams, light their towns, pump water or sewage and, later, recharge electric vehicles. In 1914, there were 338 municipal incinerators in towns and cities throughout the United Kingdom. There were 295 with boilers to recover heat of which 77 also generated electricity. From the 1930s onwards incineration of municipal waste developed throughout the world. The recovery of heat from the combustion of clinical waste is well understood and is now practised throughout Europe. For example, the "state-of-the-art" pyrolytical incinerator facility in the Netherlands illustrates that, with proper engineering design, pyrolysis and gasification can be used for the successful treatment and disposal of clinical waste with environmental benefit. This long history and experience has demonstrated the reliability of the incineration technology.

5.5 THE HANDLING OF RESIDUES AND FURTHER TREATMENT REQUIREMENTS PRIOR TO FINAL DISPOSAL

5.5.1 One of the factors relevant to the treatment of clinical waste by most alternative technologies (wet thermal treatment, chemical treatment and microwave) is that the waste after treatment is wet. This may require the treated waste to be dried or contained in leak-proof containers prior to delivery to a landfill site or Waste-to-Energy plant.

5.5.2 Another problem arises when the waste is not rendered unrecognisable by the treatment system before it is transported to the landfill site. There is likely to be very strong public reaction if the media or the general public see the residuals irrespective of whether the residuals have been disinfected (see section 5.6 on public perception of risk). This is because it is not possible to

determine visually whether the residuals have been disinfected. Whereas if the waste has been treated by incineration, gasification, pyrolysis or plasma technology, the clinical waste will be converted into ash and rendered unrecognisable. It will be obvious to the casual observer that the clinical waste has been heat-treated and thus rendered sterile.

5.5.3 As clinical waste treated by alternative technologies (autoclave, microwave and chemical treatment) would still contain residual amounts of wide arrays of chemicals, pharmaceuticals and cytotoxic drugs and produce bad odour, the treated clinical waste should be properly labelled, packaged, transported and disposed (Ontario EPA, 1994). For incineration, gasification, pyrolysis or plasma-based technology, the amount of residue is greatly reduced. However, it may be necessary to further treat the ash by solidification to reduce its metal leaching properties.

5.6 SPACE REQUIREMENTS

Space for treatment equipment

5.6.1 The space required for an autoclave with a treatment capacity of 600 tonnes per year is as follows: the autoclave itself measures 2 m in diameter by 5 m in length. The space required to site and operate the plant, the shredder or grinder and other ancillary equipment is approximately 100 square metres and a further 100 square metres to store the wheeled containers (transit skips) for holding untreated and treated clinical waste.

5.6.2 The space requirement for an autoclave, microwave or chemical treatment plant would be very similar except in the case of a chemical treatment plant, approximately 25 square metres would be required for safe storage of the chemicals.

Ancillary space

5.6.3 The Clinical Waste Control Scheme for Hong Kong proposes that all the clinical waste from all the hospitals and clinics will be treated by the CWTC. The population of HK is 7 million at the moment and 8 million in 10 years time. If there is to be a central facility or several regional facilities in HK, the clinical waste will need to be transported to the facility contained in rigid transit skips in accordance with the United Nations recommendations. The number of skips used by the hospitals, clinics and collectors will be very significant. Facilities will be also required to clean and disinfect the skips automatically either on site or at other premises. The management of the skips will be a significant factor in the use of space since they have to be stored both at the hospitals and at the treatment facility before and after treatment together with a supply of spare skips in case of damage.

5.6.4 To handle the clinical waste in bulk in a cost-effective manner and reduce manual handling, it is necessary to provide equipment for loading the skips and feeding the waste into the treatment compartments automatically.

Considerable space should also be provided.

5.6.5 A site of around 200 square metres for the treatment plant together with ancillary space for holding and disinfecting skips may be difficult to find in the hospitals or clinics in Hong Kong where space is at a premium. The space required for other alternative technology plants, the ancillary equipment and the storage area for the filled containers awaiting processing is unlikely to be less than the 200 square metres shown above and could be more. Equally it is unlikely to be much less than that required for an incineration plant with the same throughput. This is certainly the case if the facilities are to be sited in a hospital. Access to the facility would also be a big problem if a regional treatment facility is located within a hospital setting in HK.

5.7 **PUBLIC PERCEPTION OF RISK**

5.7.1 **Risks from clinical waste**

The EC Priority Waste Stream Project Management team investigated the risks from clinical wastes and arrived at a view that is shown below. In general, risks can be divided into 2 groups, perceived risk and actual risk:

Perceived risk

A risk, whether real or not, which the public or health or environmental professionals, believe may result from clinical waste or its disposal, apart from any scientific validation of the risk.

Emotional risk

An emotional risk is a perceived risk. Commonly, where the level of risk is increased due to the emotional response of individuals to a prevailing situation which has offended their sensibilities or ethics.

Actual risk

Risk which is known to exist and for which a probability can be measured or inferred.

Risk of infection

An actual risk presented by pathogenic micro-organisms, exposure to which could result in an infection.

Toxic risk

An actual risk presented by any substance (drugs or not), exposure to which could provoke anatomical or functional harm.

Physical risk

An actual risk is one of accidental bodily damage or laceration that may or may not lead to subsequent infection.

5.7.2 Most people react when faced with waste from the treatment of human beings. Their disgust or repulsion, as when in contact with most types of waste, is related to their personal sensibility and ethics, and to the collective imagination; the experience has social and cultural connotations. People close

enough to see, smell and touch the waste are likely to be more deeply affected. This psycho-emotional threat would be independent of any scientific validation or refutation of risk. The sense of threat might continue to exist, therefore, even when the hazard is shown not to exist.

Health workers' perceptions may be due to the difficulty of making a logical scientific analysis of the risk. This lack of knowledge nevertheless means that people tend to see all clinical waste as health risk. The logic of the deeply felt risk thus tends to increase the quantities of risk unless some scientific check is imposed.

5.7.3 If the people not working in healthcare sector still perceive a serious risk from clinical waste, it may be explained thus:

- the probable consequence of some diseases is death (AIDS);
- the non-expert is not in control of the risk (micro-organisms which carry infections are invisible);
- waste is an intuitively plausible link in the chain of infection;
- non-experts cannot distinguish between the basic and sensational information; and
- identifying who or what is "responsible" for the risk (person, institution, or industry) is difficult.

5.7.4 Risks from the treatment and disposal of clinical waste

Perceived risks are also related to the ways in which clinical waste may be processed:

- **Landfill** is seen as hazardous to the environment, particularly to health, fauna and flora, and groundwater. Unregulated landfilling is seen as more hazardous than regulated landfilling. Landfilled clinical waste is also seen as providing a culture medium for pathogenic micro-organisms .
- **Composting** is seen as hazardous to health and the environment, on the supposition that compost might be contaminated by pathogenic micro-organisms from the waste.
- **Alternative treatment technologies.** These were not considered in the EC Project risk assessment but health workers perceive them as a risk by being source of Volatile Organic Compounds and other toxic substances through air emissions when sited in hospitals. The general public will also have the same perception of risk similar to those when dealing with clinical waste at any facility.
- **Incineration on hospital sites.** People in the neighbourhood of hospitals tend to see the hospital incinerator as a hazard to their health and environment.
- **Centralised incineration.** People also, however, tend to assume that big technology entails big risk. Centralised incinerators are much larger than on site incinerators and so perceptions of greater risk are naturally attached to them. The perception is aggravated when the central incinerator processes clinical waste rather than household waste.

5.7.5 The gap between non-experts and experts lies in the comprehensiveness of their conception of risk. To experts, risk is a calculated value derived from observed mortality or morbidity; for non-experts the calculated value is altered by their judgement of, or outrage over, a publicised event or controversy.

5.7.6 A perceived risk may still be a real risk. The preponderance of needle stick accidents do not result in a hepatitis B infection, but some do. Nevertheless the hazards most feared by non-professionals do not necessarily pose the greatest risk. Subjectivity and emotion affect the perception of risk from clinical waste.

5.7.7 Industry has identified over 20 "outrage" factors in the non-expert perception of events. They include:

- **Free will.** A voluntary risk is more acceptable than an imposed risk: e.g. mountaineering.
- **Control.** Someone who imagines he controls the outcome is more tolerant of risk: e.g. driving vs. flying.
- **Fairness.** The public may expect, or accept, that people facing greater risk will get greater benefits: e.g. the x-factor in military pay.

Discussion

5.7.9 The perception of risks associated with the treatment and disposal of waste particularly clinical waste is heightened in the minds of the general public as shown in the extracts from the EC Priority Waste Streams Project Report. The NIMBY (not in my back yard) syndrome is well understood by waste management professionals and it is only by being transparent in all dealings with the public can this syndrome be overcome. There are particular problems in dealing with incineration plant mainly due to the gap between the professionals and the general public. To experts, risk is a calculated value derived from observed mortality or morbidity; for non-experts the calculated value is altered by their judgement of, or outrage over, a publicised event or controversy. The publication of outdated or erroneous data, which can be given a spin by some parties, can affect the perception of the general public and this should be taken into account when dealing with any proposal to install and operate any new facility. The general public is not the only stakeholder that perceive risk and object to a clinical waste treatment facility, the clinical professionals and other workers also perceive risks to their health and well-being associated with the siting of alternative technologies within the hospitals if they know that VOCs may be released in the hospital environment. This is heightened by the fact that they do not have sufficient information to make a logical evaluation of the risk.

5.8 SUMMARY

5.8.1 The disposal of untreated clinical waste in landfill is an option only where the authorities genuinely lack the means or where the level of waste management is still in a very early stage of development and even then proper

control has to be undertaken. In the European Union (EU) it is illegal to place untreated clinical waste into landfill sites.

5.8.2 Incineration of clinical waste has a long history. Over this time, data and information have been collated, analysed and evaluated. The proposed EU Directive on waste incineration comes directly out of this long-standing and well-documented dependence on incineration. Similarly, the scientific testing protocols have undergone significant developments to match the exacting emissions and environmental standards. Incineration still remains the most effective means of disposing of all clinical waste.

5.8.3 In comparison, alternative and novel technologies for the treatment of clinical waste are still in the development stage notwithstanding their rapid emergence over the past 20 years. In summary, it should be noted that:

- a). The efficacies of killing microorganisms by alternative technologies, unlike high temperature incineration, depend very much on operational conditions and nature of clinical waste. Details protocols to assess such efficacies have to be developed. However, the protocols have only been operating for the past ten years and these too, like the technologies they were set up to regulate, are still in the development stage. Furthermore, there are no international standards for efficacy testing or emission standards for the alternative and novel treatment technologies at the moment. The STAATT which is the best available standard for efficacy testing is still under development.
- b) Researchers studying the alternative technologies have discovered that there is a scarcity of independent research into their effects upon the environment and human health.
- c) The limited research that has been carried out indicates that there are a variety of VOC's and other chemicals emitted during the process and the amounts and types vary on a day-by-day basis. Hundreds of chemicals are used in the hospitals and clinics. These include pharmaceuticals, cytotoxic drugs, disinfectants, bacteriological sprays, ointments, sterilising agents etc. Tens of thousands of other chemicals and pharmaceuticals are also being tested in pre-clinical and clinical research laboratories associated with hospitals and universities. Whilst expired chemicals should be separately collected as chemical waste, such chemicals may still be present in small/residual amounts in the used syringes, 'empty' ampoules, swabs or soiled dressings, animal beddings etc.
- d) The inability of destroying or removing such chemical contaminants by alternative technologies should be considered. For any communal treatment facility, it would have to handle waste arising from various sources which may comprise ampoules and syringes contaminated with pharmaceuticals, chemicals, cytotoxic drugs, and disinfectants, and infectious or chemically- contaminated animal carcasses and beddings arising from medical research, in addition to human tissues and

amputated organs, soiled dressings contaminated with blood and other body fluids, sharps, infectious agents, microbiological cultures etc. Since it is improper and not practicable for the operators of treatment facilities to inspect every bag of clinical waste and confirm the absence of pharmaceuticals, chemicals or broken thermometers before treatment by alternative technology, toxic vapour will be given off during autoclave or microwave treatment if the hazardous materials are improperly segregated and find their way into the clinical waste stream. On the other hand, disposal of clinical waste by high temperature incineration may provide for a fail-safe solution.

- e). Whilst the limited tests carried out by NIOSH (NIOSH, 1997) inside the selected treatment facilities indicated that the discharges were within the threshold limit values of that country,
 - no tests had been recorded outside such facilities (as evaluating the environmental impacts of such facilities is not under the purview of NIOSH); and
 - the cumulative impact of the wide arrays of residual chemicals on health and safety is not known.

- f) With respect to the protection of the environment and harm to human health, sufficient independent work has not yet been carried out to develop protocols for this. For example, the Environment Agency for England and Wales has yet to consult its proposal for the control of the alternative and novel technologies. The recent CDC's report of occupational acquired tuberculosis of 3 workers (including one worker with multiple drug resistant) in an alternative treatment facility in USA (NIOSH, 1998; WHO, 1999c; Johnson et. al., 2000), where alternative technologies are developed and used more than any other countries, indicated that worker's health should not be overlooked in adopting a particular technology. The risk of occupational acquired infections in clinical waste disposal facility is more real than the perceived risk of dioxin formed during clinical waste incineration.

- g). Novel technologies have presently neither the track record nor the regulatory framework to be considered as a serious contender at this stage.

5.8.4 A broad comparison of the various treatment technologies is presented in Table D.

TABLE D BROAD COMPARISONS OF DIFFERENT TECHNOLOGIES OF CLINICAL WASTE TREATMENT

COMPARISON CRITERIA	AUTOCLAVE/WET THERMAL TREATMENT	ELECTROMAGNETIC WAVE (MICROWAVE AND RADIOWAVE)	CHEMICAL DISINFECTION	HIGH TEMPERATURE INCINERATION
Destruction of infectious microorganisms <ul style="list-style-type: none"> Efficacy Factors affecting efficacy 	<ul style="list-style-type: none"> Good - can achieve Level III destruction of infectious microorganisms Temperature and pressure Improper packaging may affect steam penetration; 'cold' spot may happen. Shredding required to improve efficacy Length of treatment cycle Incomplete air removal from chamber may affect steam sterilization Size of waste load 	<ul style="list-style-type: none"> Good - can achieve Level III destruction of infectious microorganisms Microwave source strength Duration of microwave exposure Extent of waste mixture Moisture content of waste Shredding for improving efficacy Reported that microwave efficiency will decrease if liquid content of waste > 10%, metal content > 1% or metal pieces > 0.2 kg 	<ul style="list-style-type: none"> Good - can achieve Level III destruction of infectious microorganisms Chemical concentration Temperature pH Contact time with chemical Adequate mixing with chemicals is essential. Shredding is therefore important Disinfectants may be interfered by organic components of waste 	<ul style="list-style-type: none"> Very Good - fully destroy infectious microorganisms Adequate mixing Moisture content of waste Filling of combustion chamber Residence time
Destruction of sharps	<ul style="list-style-type: none"> Cannot destroy sharps 			<ul style="list-style-type: none"> Incineration destroys all sharps and make waste unrecognizable
Destruction of body parts	<ul style="list-style-type: none"> Not suitable to treat body parts due to cultural practice 			<ul style="list-style-type: none"> Incineration destroys all body parts and make waste unrecognizable
Destruction of residual amounts of cytotoxic drugs and pharmaceuticals	<ul style="list-style-type: none"> Cannot destroy residual amounts of cytotoxic drugs and pharmaceuticals in clinical waste 			<ul style="list-style-type: none"> Incineration can destroy all residual amounts of cytotoxic drugs and chemicals in clinical waste
Impacts on the Environment	<ul style="list-style-type: none"> May generate toxic volatile organic compounds, carcinogenic formaldehyde, mercury vapour and other un-characterized air emissions Generate objectionable and foul odour Generate wastewater from condensate. Wastewater may be regarded as chemical waste and treated as such Treated waste may still contain residual amounts of chemicals, pharmaceuticals, mercury and cytotoxic drugs which may need proper handling. 	<ul style="list-style-type: none"> May generate toxic volatile organic compounds, carcinogenic formaldehyde, mercury vapour and other un-characterized air emissions Small amount of wastewater may be produced from condensate. Wastewater may be regarded as chemical waste and treated as such Treated waste may still contain residual amounts of chemicals, pharmaceuticals, mercury and cytotoxic drugs which may need proper handling. 	<ul style="list-style-type: none"> May generate toxic volatile organic compounds, carcinogenic formaldehyde, mercury vapour and other un-characterized air emissions Disinfectants may react with residual chemicals to produce unknown chemicals Very large amount of wastewater will be generated. Wastewater may be regarded as chemical waste and treated as such Treated waste may still contain residual amounts of chemicals, pharmaceuticals, mercury and cytotoxic drugs which may need proper handling. 	<ul style="list-style-type: none"> Toxic volatile organic compounds will be incinerated. However, dioxins and mercury vapour may be formed All air pollutants should be removed by appropriate pollution abatement equipment
Handling of waste treatment residues	<ul style="list-style-type: none"> Treated wastes should be landfilled or incinerated in MSW Incinerator Treated wastes which may be contaminated with residual amounts of chemicals, pharmaceuticals and cytotoxic drugs should be properly disposed 			<ul style="list-style-type: none"> Bottom ash should be disposed of in sanitary landfill

COMPARISON CRITERIA	AUTOCLAVE/WET THERMAL TREATMENT	ELECTROMAGNETIC WAVE (MICROWAVE AND RADIOWAVE)	CHEMICAL DISINFECTION	HIGH TEMPERATURE INCINERATION
Volume reduction of treated waste	<ul style="list-style-type: none"> Cannot significantly reduce volume of waste unless shredder or compactor is used 			<ul style="list-style-type: none"> Incineration reduces volume of waste without shredding
Weight reduction of treated waste	<ul style="list-style-type: none"> Cannot reduce weight of waste. Weight may be increased due to addition of water/steam or chemicals 			<ul style="list-style-type: none"> Incineration reduces weight of waste by more than 80%, depending on the content of combustible materials.
Operational safety and health issues	<ul style="list-style-type: none"> Shredding of bags of clinical waste for better penetration of steam may lead to production of microbial aerosols and need proper control Maintenance of shredders contaminated by clinical waste may pose occupational safety and health risks Autoclaves working under high pressure need to be carefully control as required under the Boiler and Pressure Vessel Ordinance 	<ul style="list-style-type: none"> Shredding of bags of clinical waste for even heating of waste may lead to production of microbial aerosols and need proper control Maintenance of shredders contaminated by clinical waste may pose occupational safety and health risks Microwave and radiowave that cannot be detected by human senses, can pose significant health risk if leakage occurs. Leakage has to be monitored continuously in the workplace 	<ul style="list-style-type: none"> Shredding of bags of clinical waste for exposure of waste to chemicals may lead to production of microbial aerosols and need proper control Maintenance of shredders contaminated by clinical waste may pose occupational safety and health risks Many disinfectants are hazardous or toxic and need proper storage and careful handling 	<ul style="list-style-type: none"> No shredder is required and hence does not have microbial aerosol problem created by the use of shredders Fire hazard should be properly controlled
Reliability and ease of maintenance	<ul style="list-style-type: none"> Hard objects in waste may pose problems to shredder. Other comparative information not available 			<ul style="list-style-type: none"> Technology well known and developed for over a hundred years No shredder problem
Capital cost of facility	<ul style="list-style-type: none"> Relatively lower 	<ul style="list-style-type: none"> Relatively higher 	<ul style="list-style-type: none"> Relatively higher but may be lower than modern incinerator 	<ul style="list-style-type: none"> Relatively higher
Waste treatment costs	<ul style="list-style-type: none"> Relatively lower 	<ul style="list-style-type: none"> Relatively higher 	<ul style="list-style-type: none"> Relatively higher 	<ul style="list-style-type: none"> Relatively higher
Space requirements	<ul style="list-style-type: none"> Same for both autoclave and electromagnetic wave facilities 			<ul style="list-style-type: none"> More than others due to presence of air pollution abatement equipment
<ul style="list-style-type: none"> Equipment 	<ul style="list-style-type: none"> Same for all facilities as they all need waste storage areas, storage areas of transit skips for all hospitals and clinics, area for cleaning and disinfecting skips, areas for safety equipment, reception area for waste collecting vehicles and facility to weigh vehicles and skips, cold storage area for holding human organs, general ventilation and odour control facilities etc 			
<ul style="list-style-type: none"> Ancillary 				
Public perception	<ul style="list-style-type: none"> Unlikely attract attention from public and green groups due to lack of information on documented health risk studies Hospital workers may disagree with the siting in hospitals 			<ul style="list-style-type: none"> Public perception of risk always lead to objection from the local residents and green groups
Further treatment requirements prior to final disposal	<ul style="list-style-type: none"> Shredding and compacting/baling prior to delivery to landfill Waste should be dried or transported in watertight vehicle/container before delivery to landfill 			<ul style="list-style-type: none"> Shredding and compacting/baling of waste not required before delivery to landfill
Others	<ul style="list-style-type: none"> Autoclave is a traditional method for treating microbiological cultures in clinical laboratories Medical institutions are familiar with this method 		<ul style="list-style-type: none"> Some facilities require patented disinfectants which may be expensive and not flexible in the use of other chemicals 	<ul style="list-style-type: none"> There is potential to recover heat. Can treat all clinical waste types without stringent segregation of waste within hospitals and clinics

CHAPTER 6 REVIEW OF INTERNATIONAL PRACTICES

6.1 EUROPE

Background

6.1.1 Nearly all environmental legislations for the countries within the European Union (EU) is decided by the EU and implemented in local legislation after a Directive is passed by the EU. "Towards Sustainability" is the European Community Programme of policy and action in relation to the environment and sustainable development (is better known as The Fifth EC Environmental Action Programme). The general approach and strategy of the Fifth Environmental Action Programme which was approved by the Council and the Representatives of the Governments of the Member States on February 1 1993, differs from previous programmes as its title 'Towards Sustainability' implies, the programme sets longer term objectives and focuses on a more global approach.

6.1.2 One of the key precepts of the Action Programme is the sharing of responsibility, which requires dialogue and action by all partners in society. The Action Programme, as far as waste management is concerned, means putting into practice the Commission of the European Communities' "European Community Strategy on Waste Management" which was approved by the Council, of what is now, the European Union (EU) in September 1989.

6.1.3 One of the methods devised to implement the strategy was to select certain priority waste streams one of which was for Health Care Waste (HCW) and to apply the hierarchy or "ladder principle" for dealing with the waste. Top priority is to prevent waste being produced and the order of priority is shown below; dumping of untreated HCW is of course unacceptable and does not appear on the list.

- 1) Prevent
- 2) Re-use
- 3) Recycle
- 4) Incinerate (with heat recovery)
- 5) Incinerate
- 6) Landfill

6.1.4 In order to implement the Strategy for Waste Management (particularly for the Priority Waste Streams), which takes into account of the hierarchy approach, it is necessary for the Commission of the European Communities (CEC) to seek environmentally acceptable solutions. This was carried out in the case of the Priority Waste Streams with the groups and organisations that directly influence the production and consumption patterns ahead of the waste production stage in order that results can be achieved in the short term and behaviour patterns changed in the long term.

6.1.5 This approach depends upon thorough discussion taking place at EU level with the parties most affected by a particular priority waste stream. Independent consultants take part in the project to ensure that the strategic discussion is properly monitored and a consensus arrived at.

6.1.6 When properly carried out, this approach is likely to ensure maximum participation and lead to everyone fulfilling their responsibilities in achieving "sustainable development" in accordance with the CEC Waste Strategy. The HCW Priority Waste Stream Project Group was a representative group of manufacturers, producers, users, waste managers, environmental protection and recycling groups together with representatives of the Member States and with the support of the Commission and Consultants. In addition a reference network was established enabling all interested parties to participate. The HCW reference network had almost 300 members from 25 countries both within and outside of the EU. The HCW Project Group first met in June 1992 and completed a programme of work leading to a strategy and implementation programme, which could be develop into EU legislation. In the case of HCW, the work of priority Waste Stream Project has not been turned into legislation and the work is now out of date. Nevertheless the information contained therein has been very useful both nationally and internationally and has made a significant contribution to the database, which for this waste stream is generally accepted as being small and unfocused. Four Directives are particularly important as far as the countries in the EU are concerned. They are:

- The Framework Directive on Waste
- The Landfill Directive
- The Hazardous Waste Directive
- The proposed Waste Incineration Directive

6.1.7 The Framework Directive has been in force and amended a number of times since 1975. The Landfill Directive, which is in the process of being implemented in the countries in the EU specifically, excludes the landfilling of hospital or other clinical wastes arising from clinical or veterinary establishments which are infectious. (Infectious is as defined in the Hazardous Waste Directive.) All Directives are mandatory on all Member States of the EU and they have to implement through their own legislation within the time scale set by the Directive. The exclusion of infectious waste is one of many stringent requirements for landfill, which also includes a programme for reducing the amount of municipal biodegradable waste going to landfill to 35% of the 1995 amount. The proposed Waste Incineration Directive is to prevent, or where that is not possible to reduce as far as possible, the environmental impacts of emissions into air, soil, surface water and groundwater and the resulting risks to human health from the incineration and co-incineration of waste. Stringent operational conditions and technical requirements are set out as are emission limit values for waste incineration. When implemented this Directive will have a considerable effect on the way in which HCW is dealt with in the EU in the future (see 6.1.18). No timetable for the adoption of the Directive has yet been drawn up.

Germany

6.1.8 Germany has an estimated population of just over eighty million. Germany is highly urbanised, with about 85 per cent of the people living in communities of at least 2,000 people. The principal city is Berlin the capital of Germany with a population of about three and a half million.

6.1.9 In 1984 there were 554 on-site hospital incineration plants. By 1987 this had declined to 218 and at the moment there is only one hospital (Heidelberg) with a hospital waste incinerator and this one may be closed at the end of this year. Except for the hazardous waste incineration plants, there is only one off-site commercial incinerator in Kiel and two separate treatment units in Augsburg and Bielefeld in combination with a municipal waste incineration plant. Non-infectious clinical waste (German definition) from patient care is normally burned in all of the about sixty municipal waste incineration plants in Germany. Microwave and wet thermal treatment systems are in use in Germany but the exact numbers are not known. However the number in use is decreasing due to over capacity of the regional hazardous waste incinerators. The cost per tonne of incinerating clinical waste has been structured so that it is attractive to use these hazardous waste incinerators for clinical waste. For details of the situation in Germany see Table E.

TABLE E Overview of Plants for the Thermal Treatment of Infectious Waste, Human Organ Waste and Body Parts From Hospitals and Other Healthcare Establishments in Germany (Date: 08/2000)

Incineration plants for infectious waste or plants with special incineration chambers/ units for the incineration of infectious waste	Hazardous waste incineration plants burning infectious waste together with other hazardous waste	Special plants for the disinfection of infectious waste
Augsburg Treated waste in 1999: 1,373 tonnes Bielefeld Treated waste in 1999: 1,516 tonnes Kiel-Wellsee Treated waste in 1999: 527 tonnes Heidelberg Treated waste in 1999: 400 tonnes (treatment capacity: 2000 t/year)	Bergkamen, Biebesheim am Rhein, Burghausen, Frankfurt am Main, Hamburg, Herten, Krefeld, Leverkusen, Ludwigshafen , Marburg, Schwedt/Oder, Wesseling, Dormagen, Schwarzheide, Baar-Ebenhausen, Schöneiche	Braunschweig, Zwönitz, Frießnitz Treatment capacity: approximately 800 – 1,000 t/year Leipzig Freital Treated waste in 1999: 52 tonnes Münster Treatment capacity: approximately 130 t/year

France

6.1.10 France is a member of the European Union and has an estimated population of 58 million with over 9 million living in the metropolitan Area of Paris, over 1.2 million in Greater Marseilles, and over 1.2 million in Greater Lyon. The current situation in France with respect to clinical waste is that most clinical waste is incinerated:

Technologies	Number	Annual Tonnage of HCW
On-site hospital incinerator	1	Not known
Off-site incinerator	3	40,000
Municipal incinerator	19	90,000
Thermal treatment	20	22,800

Greece

6.1.11 Greece is a country of mostly small towns and villages. It has a population of just under 10.5 million. Much of the urban population is concentrated around Athens the largest and most important city as well as being the capital, with a population of 3 million. The other large urban area is Thessaloníki, with a population of nearly 400,000.

6.1.12 A recent survey (1999) gave the following results:

- According to the national planning of the Ministry of Environment, which is based on an older (1986) study, central clinical waste incinerators are to be built in the main Districts of Greece.
- A new clinical waste incinerator is now under construction by the Union of Municipalities of the Major Athens Area. It consists of two units (one as stand-by), each with a capacity of 15 tonnes/day. A second incinerator, for the District of Central Macedonia, in Thessaloniki, is in the design phase. It consists of two units (one as stand-by), each with a capacity of 7.5 tonnes/day.
- Flue gases will comply with the EU Guideline for toxic waste incineration.
- Only a few large hospitals in isolated areas will continue to operate the on-site hospital incinerators.
- The “Ministerial Decision on the Management of Hospital Waste in Greece” is still under preparation and is expected to be published before the end of this year.
- The total number of hospital beds in Greece is 58,000-60,000. In many older hospitals the incinerators are not operating any more.
- Five hospitals with about 2,500 beds each have an incineration plant that is still operating and five hospitals with about 2,000 beds have an incinerator under construction.
- There still exists a small (700 kg/day) central incineration unit in Athens, serving a small group of hospitals and operated by the Union of Municipalities of the Major Athens Area.
- At the moment most clinical waste is disposed of in landfill sites, together with the municipal waste.

Ireland

6.1.13 The island of Ireland is divided into Northern Ireland, a constituent part of the United Kingdom, and the Republic of Ireland. The island is divided into four historical provinces—Connaught, Leinster, Munster, and Ulster—and administrative units called counties. The Republic of Ireland consists of Connaught, Leinster, and Munster provinces, totalling 23 counties and, in the north, the 3 counties of Ulster form the Province of Northern Ireland. The responsibility of dealing with clinical waste management in the whole island for the two jurisdictions is that of the Joint Waste Management Board (JWMB). The population of Northern Ireland is 1.6 million and that of the Republic 3.5 million.

6.1.14 A solution for clinical waste management in Ireland has been accepted by the JWMB and will be provided by a private company Sterile Technologies Ireland Limited (STI). It depends on the provision of two alternative technology systems sited in the Republic and an incineration plant located on a hospital site in Northern Ireland which will be used for disposing the waste that cannot be treated by the alternative technology. One alternative technology plant has been erected in Dublin and the other plant will be located in Tipperary. The existing incineration plant will continue to operate and will be upgraded as necessary to meet the legislation. The alternative technology that will be used is the Chem-Clav process. The process consists of a two-stage shredding/pulverising process with simultaneous introduction of a disinfectant sodium hypochlorite. This sanitises both the equipment and the clinical waste. The equipment next separates for re-circulation excess fluids from the solid waste using an auger press. The surface of the solid waste now has a coating of the chemical; it is then introduced into an encapsulated auger where under temperature-controlled conditions, multiple port injections of steam go directly onto the remaining waste resulting in its sterilisation. The residual waste, now sterile and unrecognisable, can either be sent to sanitary landfill or depending on circumstances, recycled. The resultant waste product is nearly dry and reduced in volume by 90%.

Netherlands

6.1.15 The Netherlands has a population of just over 15 million. The nation is heavily urbanised with some 90% of the population live in towns and cities. The Netherlands is a member state of the European Union. Incineration is the only method in use in the Netherlands and no alternative technology is being used for the disposal of clinical waste.

6.1.16 All clinical waste produced in the Netherlands is treated in the "state of the art" thermal treatment plant (pyrolytical incinerator) operated by the Company Zavin. The plant is sited together with a municipal Waste-to-Energy plant and a sludge incineration plant in the City of Dordrecht. The heat from all three plants is transferred to a common boiler plant and turbine for the production of electricity. The three plants are owned and managed by different companies.

6.1.17 The Zavin clinical waste incineration plant can process up to 9000 tonnes of waste per annum but at the moment it only handles 6000 tonnes from the Netherlands and imports 1000 tonnes. The plant is based upon the principle of pyrolysis and gasification in the primary chamber and secondary chamber respectively. The absence of oxygen prevents incineration with flames. After the gasification stage an afterburner degrades the gases further by means of controlled incineration of the gases. The addition of natural gas is hereby minimized. The waste is reduced to 19% by weight and less than 3% by volume after treatment. It is claimed that the residue does not contain any hazardous waste and can be disposed of to landfill as an inert material. A flue gas washer is fitted to ensure the air emission fully complies with the very high standards of air quality in the proposed EU Waste Incineration Directive. The chemical and physical composition of the slag is permanently monitored and is landfilled. The fly ash and flue gas treatment residues are landfilled in a special landfill for hazardous waste in the Rotterdam region.

United Kingdom

6.1.18 In the United Kingdom, clinical waste was traditionally treated at the hospitals by on-site incineration. This began to change in the late 1980's following the rapid closure of hundreds of outdated hospital incinerators, changes in the management of the National Health Service and the introduction into the market of companies with state-of-the-art incinerators. These changes resulted in the reduction of clinical waste incinerators from 700 to 37. Today, most clinical waste is treated by incineration in the 37 incinerators, some of which may be situated in the hospitals and most of which are operated by private sector companies commercially. All these plants comply with the current legislation but it is not known whether they all will be able to comply with the proposed new EU Waste Incineration Directive without extensive improvements. The main requirement that has to be met is to achieve a level of incineration that ensures that the slag and bottom ashes do not have a total organic carbon content of more than 3%. There will be some incinerators that will be able to be easily adapted to meet the new criteria; the exact number is however not known at present.

6.1.19 There are two plants in the UK using the dry system of alternative technology, together with one microwave system and one autoclave system. The autoclave is used for treating the waste prior to incineration in a municipal Waste-to-Energy incinerator. One other municipal Waste-to-Energy incinerator also receives clinical waste in a specially designed loading system discharging the waste directly into the furnace hopper rather than the main bunker. The Environment Agency has developed interim criteria for licensing the alternative technologies and also for permitting the treatment of the clinical waste at the municipal incineration plants and will shortly be going out to consultation on three documents as follows:

- a) Advice on efficacy testing
- b) Review of alternative technologies
- c) The Agency's policy advisory document.

6.2 UNITED STATES OF AMERICA

6.2.1 The population of the USA is about 265 million and according to the US EPA First Interim Report to Congress the number of clinical waste producers from the various facilities are set out in Table F.

TABLE F USA Clinical Waste Producers

Type of Facility	Number
Hospitals	7100
Laboratories	4,300
Clinics	15,500
Physicians	180,000
Dentists	98,400
Veterinarians	38,000
Residential Care	12,700
Blood Banks	900
Funeral Premises	20,400
TOTAL	377,300

Source : USA EPA

6.2.2 In 1997 the US EPA estimated that there were 2400 hospital incinerators burning clinical waste on site, i.e. about half of the hospitals operated their own incinerators. In 1997 the US EPA issued for the first time stringent final air emission guidelines for use by States in devising their plans to reduce air pollution from existing clinical waste incinerators and to reduce air pollution from incinerators built after June 20 1996. The regulations also provided for small rural community hospitals to help reduce emissions in a way that is affordable, by setting a more relax air emission standards than those in cities. Table G sets out the number of Alternative Technology Units in use in the USA. Set out in Table H is a sample of 13 States indicating the current situation in each of those States with respect to clinical waste incineration:

TABLE G Number of Alternative Technology Units in the USA

TYPE	NUMBER OF FACILITIES
Autoclave	931
Chemical Treatment	173
Heat Steam Thermal Treatment	92
Electro-Thermal Radiation	5
Microwaves	254
Novel Technologies	61
TOTAL	1516

Source : Jane Rubenstein 1997, Data Source Environmental Industries Association.

TABLE H Survey Results on the use of Incineration for the disposal of Clinical Waste in the USA

State	Hospital On-Site Incinerators	Off Site Incinerators	Status of State Plans	Comments
Alabama	34	1	Final Plan under Review	There will be a closure of all but one of the on-site incinerators when the EPA Emissions requirement comes into force on June 9 th 2001
Florida	28	4	No submission	The 28 hospital incinerators are likely to close and the waste disposed of at the 4 off-site centralised incinerators
Georgia	62		Final Plan under Review	These all were permitted but it is not known how many are still in use
Michigan	43	1	Draft Plan Available	
New Jersey	15		Draft Plan Available	
New York State	13	1	State Plan Approved	
Ohio	23		Draft Plan Available	
Oregon		1	Negative Declaration	
Pennsylvania	40		Final Plan under Review	
South Carolina	2		No submission	
Vermont	0	0	Negative Declaration	All Clinical Waste is disposed of out of State
Virginia	3		Draft Plan Available	
Wisconsin	5		No submission	One to close shortly
Wyoming	4		Final Plan under Review	Compliance date for the EPA requirements 15.9.2000

Source: Compiled by Torgam Developments Ltd
(<http://www.epa.gov/ttn/uatw/129/hmiwi/planstat.html>)

6.2.3 From the survey it is clear that there are still many on-site hospital waste incinerators operating. The situation with respect to the State plans for Clinical Waste in October 1999 is shown in Table I. A draft plan is first submitted to the EPA and may be accepted or rejected. It is expected that as the State plans are implemented the number of hospital incinerators will decrease dramatically (estimated by the US EPA as between 50%-80% of the existing 2400) and be replaced by other larger modern incinerators and

alternative treatment facilities which will most probably be operated by private companies.

Table I USA Status of State Plans for Clinical Waste

	Draft Plan Available	Final Plan under Review	State Plan Approved	Negative Declaration (No incineration plants)	No Submission
No. of States	12	10	7	4	33

Source: USEPA Web Site

6.3 **FAR EAST**

Australia

6.3.1 The Commonwealth of Australia is made up of six states as follows: New South Wales (NSW), Queensland, South Australia, Tasmania, Victoria, and Western Australia and two territories, the Australian Capital Territory (ACT) and the Northern Territory. It has a population of approximately 18 million. Sydney has a population of over 3.7 million and also contains the world's largest area of suburbs. The other cities are: Melbourne over 3.1 million, Brisbane over 1.4 million, Perth over 1.2 million, Adelaide over 1 million, Hobart over 200,000, and Canberra, a population of 325,000.

6.3.2 The Australian and New Zealand Clinical Waste Management Industry Group (ANZCWMIG) was formed to develop and promote consistent standards for the management of Clinical and Related Wastes based on "best practice" for its members. Membership of the ANZCWMIG is from waste transporters/disposal operators, waste generators, tertiary institutions, clinical device manufacturers and other stakeholders. The ANZCWMIG has recently published a revised "Industry Code of Practice for the Management of Clinical and Related Wastes". The revised Code of Practice was launched at the Enviro 2000 Conference of the Waste Management Association of Australia in April 2000 (this conference was held in conjunction with three other conferences – Waste Water, Greenhouse Gas and Odour Control).

6.3.3 In developing the Code of Practice, the ANZCWMIG sought comments from a diverse range of stakeholders. They include government agencies, professional associations and individual waste generators. In addition, this Code of Practice has been written with due account of the National Health and Medical Research Council "National Guidelines for Waste Management in the Health Care Industry" and all State/Territory requirements.

6.3.4 The generally accepted title for this waste type is Clinical and Related Wastes (Related Wastes refer to wastes such as pharmaceutical/cytotoxic and radioactive wastes). However, due to the legislative structure of Australian

Commonwealth, State and Territory governments, each State/ Territory enacts laws pertaining to waste management – in this instance for Clinical and Related Wastes. Therefore, there are a number of State and Territory governments who name this waste differently. However, they all have given an indication to put into place the necessary actions to ensure that the amended titles to achieve consistency – thus the waste should be known as Clinical and Related Wastes.

6.3.5 The use of technologies other than incineration is relatively new within Australia but does appear to be growing. The EPA within each State/Territory licences the operation of the treatment technology and thus if one State has approved a technology, it then tends to be market forces determining the success of it in other States. The following is a brief summary of the current situation with regard to treatment technologies within Australia:

- a) **Incineration**
There are seven high temperature incinerators in use in Australia. There is at least one incinerator in each of the five mainland States and there is one in use in the ACT.
- b) **Autoclave**
Autoclave treatment has been approved for treating clinical waste, and is being used in Queensland (2 units) and NSW (1 unit).
- c) **Chemical Treatment**
Grinding/Shredding and Treatment with sodium hypochlorite (bleach) has been approved in Victoria, NSW, Queensland and New Zealand. There is one unit in use in Victoria and two in New South Wales. Grinding/Shredding and Treatment with hydrogen peroxide and lime (known as Matrix) (See 4.2.1.5 (b)) has limited approval for use in Queensland as it is still in the experimental stage.
- d) **Microwave**
Microwave Disinfection is approved for use in NSW where there is one system in use.
- e) **Landfill**
Generally landfill of untreated clinical waste is not acceptable and is for final disposal only after treatment. However, there is some limited landfilling of untreated clinical waste in rural NSW and minimal amounts in remote areas of Australia.

6.3.6 Cytotoxic wastes, pharmaceutical drugs and all chemicals have to be separated from the clinical waste stream for separate disposal by incineration at a facility that is licensed by the relevant EPA; such facilities have to achieve 1100°C in the secondary chamber and has installed appropriate pollution control equipment. All incineration facilities except in ACT, are privately owned and operated. Private companies operate all of the alternative technology plants. Alternative technology treatment licences generally do not allow the treatment of pharmaceuticals; they have to be separated out by the

waste generator.

6.3.7 Due to the Australian Constitution, restriction on trade between the States/Territories is not allowed. Therefore, Clinical and Related Wastes can and does, pass States/Territory borders for treatment. However, a generator cannot send waste to another jurisdiction if that jurisdiction treats the waste at a lesser standard than the originating jurisdiction, thus preventing what is referred to as pollution havens.

Philippines

6.3.8 The Philippines has a population of over 65 million. The distribution, however, is uneven; large areas are virtually uninhabited, while others have a relatively high population density the population is about 50% urban. The population of the capital Manila and the metropolitan area surrounding it is nearly 8 million.

6.3.9 The Philippines installed several sets of microwave systems for clinical waste treatment in Manila during 1999. Private sector companies operate them at the moment.

Japan

6.3.10 Japan has a population of 128 million with over 78 % living in urban areas. Geographically it consists of 4 large islands and over 1000 smaller islands. Most clinical waste is being treated by some 360 incineration plants located throughout the country. A small amount is being treated by alternative treatment technologies (Japan Ministry of Health & Welfare, 2000).

TABLE J Number of Treatment Facilities for Clinical Waste in Japan

TREATMENT METHODS	NUMBER
Incineration	360
Pyrolysis	7
Autoclave	3
Dry Heat	6
Others	6
TOTAL	382

Taiwan

6.3.11 A total of 33 clinical waste incinerators, which are located either on-site or off-site throughout Taiwan, were approved for the incineration of clinical waste in 1998.

Malaysia

6.3.12 Malaysia has a population of 20 million with about half of the population living in urban areas. Three companies carry out all of the services within the hospitals and transport the waste for disposal at 8 regional incinerators and 7 on-site incinerators (Pillay et al., 1999). The incinerators use state-of-the-art technology and pollution control equipment. The regional incinerators vary in size from 200 to 500 kg /hr and the onsite incinerators vary in size from 20 to 50 kg/hr. Malaysia has a clinical waste control scheme in place.

Singapore

6.3.13 The Republic of Singapore has a population of 2.8 million. At present there are two private contractors licensed to collect and transport clinical waste from the hospitals and clinics and they both dispose of the waste at their high temperature clinical waste incinerators.

6.4 SUMMARY OBSERVATIONS

The review undertaken from a sample of countries in the Far East, Europe and North America indicates a number of important points, which are set out below:

- Incineration has been the main method of treating clinical waste in most industrialised nations (e.g. many European countries) over the years. It is still preferred as the proven and most effective means of disposal and is still widely used.
- The development of alternative technologies began in the United States probably in California mainly due to the introduction of more stringent air emission standards in that State. The use of the alternative technologies is likely to grow as the States develop their plans for tightening up control of air emissions from the hospital incinerators. However incineration will continue to play an useful role even when plans have been approved e.g. New York State.
- The introduction of alternative technologies into other industrialised countries is growing due to the increasing demand by the public for tightening up emission standards and the significant costs associated with the necessary improvements to the incineration plants.
- In cases where alternative technologies are adopted, the autoclave is usually the choice. The number of autoclaves being used is 2 to 3 times more than microwave facility (which is the second commonly used alternative method).
- In the low and middle income countries that are tackling their clinical waste problems for the first time they are likely to consider the use of the alternative technologies which are less sophisticated in operation and lower in capital costs.

CHAPTER 7 APPLICATION OF ALTERNATIVE TECHNOLOGIES: OPPORTUNITIES AND CONSTRAINTS

7.1 INTERNATIONAL BACKGROUND

7.1.1 The management of waste produced during clinical activities is a matter of only recent concern and did not emerge as an issue in its own right internationally until the 1970's. Most hospitals in developed countries had on-site hospital incinerators or boiler houses and were able to dispose of all their wastes without stringent segregation of wastes. Changes arising from social and industrial factors and the subsequent problems began to emerge from two separate and distinct causes:

- Firstly, there was a steep increase in the amount of single use plastic medical devices and equipment being introduced into the market.
- Secondly, the hospital incinerators were not designed to burn plastic waste and hence produced black smoke which attracted public concern and they were being subjected to stricter gas emission controls.

7.1.2 However the reason that it did become an international public issue was because of a number of incidents that occurred where clinical waste had been handled in a criminally irresponsible manner. These incidents were then widely reported by the media, which in turn gave rise to public concern. Instances of the mishandling of clinical waste are still being reported worldwide.

7.1.3 The general public perceives clinical waste, as being the waste stream creating the greatest risk to public health. This is further exacerbated by the adverse publicity that these incidents have caused. Therefore, although the amount of clinical waste generated is relatively small, the overall effect, if it is mishandled, is disproportionately greater.

The United Nations Conference On The Environment And Development (UNCED)

7.1.4 The UNCED in 1992 led to the adoption of Agenda 21 and the concept of "sustainable development". Sustainable development has been defined as "developments that meets the needs of the present without compromising the ability of future generations to meet their own needs". The application of sustainable development to waste management means amongst other things applying the hierarchy or "ladder principle" for dealing with waste: Finding management solutions that are as near as possible to the top of the hierarchy:

- 1) Prevent
- 2) Re-use
- 3) Recycle

- 4) Incinerate (with heat recovery)
- 5) Incinerate
- 6) Landfill

7.1.5 Three other principles - the "proximity principle" the "polluter pays principle" and the "precautionary principle"- also need to be taken into account. The proximity principle means disposing of the waste as near as possible to the point of production. The polluter pays principle means ensuring that the producer will meet all of the costs of managing the waste including the costs of regulation and control. The precautionary principle means that where risk is uncertain or unknown one must assume that the risk is significant and plan protection measures accordingly.

7.1.6 Applying the hierarchy principle to clinical waste has to be undertaken with care particularly as there may be a conflict between the effects on the environment and the protection of human health. The European Commission's Priority Wastes Stream Project on Health Care Waste considered this issue and concluded that human health must come first but every effort must be taken to reduce the risk to the environment.

7.2 LOW AND MIDDLE INCOME COUNTRIES

Over the last decade, low and middle-income countries have faced a particular problem when they have been taking on the task of developing their waste management strategies. They find that, because of its importance, the first waste stream that has to be tackled is that of clinical waste. In order to improve their arrangements they have sought assistance from the World Health Organisation (WHO), the International Solid Waste Association (ISWA) and other international organisations to plan suitable management systems and regulatory regimes. The WHO has responded to these requests for assistance by producing three important documents to assist countries to develop suitable clinical waste management systems and, together with ISWA, organises conferences and seminars to promulgate the best practices world-wide. The WHO recommends that "*The final choice of treatment systems should be made carefully, on the basis of various factors, many of which depend on local conditions.*" This is the method that has been adopted in the assessment of the situation in Hong Kong and all of the points mentioned in the WHO recommendation have been taken account of in this report. The WHO also recommends that the standards for air emissions should follow those of the USA EPA and the European Union, which will also be followed by the Hong Kong Government.

7.3 HIGHER INCOME COUNTRIES

The problems facing higher income countries are different and relate to the increased awareness among the population at large of the environmental effects of waste production both in the use of valuable natural resources and the effects of the storage, transport and disposal of waste on the environment. When companies designed products in the past, they have completely neglected to consider how the product is to be disposed of when it has reached the end of its useful life. However companies are now beginning to take waste management into account and even carry out a lifecycle analysis of their products to demonstrate their compliance with the

principles of sustainable development. The most obvious are, for example, reducing the amount of packaging, using less materials in the product, manufacturing the products using environmentally acceptable materials and reducing the chemical burden.

7.4 THE SPECIAL ADMINISTRATIVE REGION OF HONG KONG

7.4.1 Our conclusions and advice on the scope for applying various clinical waste treatment technologies to Hong Kong and the operational precautions if such technologies are adopted are based upon the information and data obtained during our research and the information on the current situation in Hong Kong.

7.4.2 Landfilling of untreated clinical waste is not an environmentally sound disposal method and should only be used if there is no other option. The existing practice in Hong Kong should only be considered as an interim measure.

7.4.3 It has been demonstrated that none of the alternative technologies is capable of dealing with all types of clinical waste and incineration will still be necessary to deal with the wastes that cannot be treated by the alternative technologies.

7.4.4 The efficacy testing of the alternative technologies is still being developed and the standards whilst agreed amongst the professionals of STAATT in the USA have not yet received national or international approval. Equally, sufficient independent research has not been carried out into the environmental and safety risks associated with the alternative technologies such as the production of Volatile Organic Compounds and the problems associated with mercury and other heavy metals if the technologies are not fitted with air pollution abatement equipment. The recent discovery of occupational-acquired tuberculosis in one of the alternative treatment facilities in USA also points to the need of careful assessment of the technology to be used.

7.4.5 Incineration is a well-established and proven technology and is still widely used to dispose of clinical waste in industrialised countries. Incineration has the smallest amount of residue and this can be disposed of safely in sanitary landfill sites. There are clearly established EU Directives on emission levels for its regulation; and in the USA, emissions are regulated on a state-by-state basis and must be strictly adhered to. It is considered that the Hong Kong CWTC can meet these emission levels at which, according to the professional bodies responsible for their establishment, no health or environmental risk is or will be involved.

7.4.6 It is considered that transparency in the environmental monitoring of the incineration plant is essential to promote public confidence and allay the perceptions of risk associated with the incineration plant. It is noted that the Environmental Performance Data of the CWTC have been published in the Hong Kong EPD's website (<http://www.info.gov.hk/epd>) and this good practice

should be continued.

7.4.7 The various constraints of applying the clinical waste treatment technologies, taking into account the local factors have been summarized in Table K below.

TABLE K Constraints of Applying Alternative Treatment Technologies in HK

Local Factors Being Considered	ALTERNATIVE TECHNOLOGIES (autoclaves, microwaves, chemical treatment)	INCINERATION AT HK CWTC
Types of Clinical Waste	- Technologies will only handle part of the clinical waste produced (Table B)	- Proposal will handle all types of clinical waste produced in HK
Clinical Waste Management Practices	<ul style="list-style-type: none"> - More stringent segregation will be required for the waste not suitable for treatment by a particular technology. This may not be feasible in the already under-staffed hospitals in Hong Kong. - Waste producers may also be required to send different types of clinical waste to different places for treatment, e.g. human body parts to CWTC incinerator and other clinical waste types to a different disposal facility. 	<ul style="list-style-type: none"> - No special segregation will be required. - There is no need to re-train all the healthcare workers on waste segregation practice.
Environmental Impacts	<ul style="list-style-type: none"> - The environmental impacts of individual technology have not been not fully evaluated. Work would need to be carried out on air emissions both within the building and outside the building. - Protocol for testing of efficacy of destroying infectious micro-organisms is still being developed and agreed. 	<ul style="list-style-type: none"> - An Environmental Impact Assessment has already been carried out and all impacts have been identified and mitigated. - Dioxin emission level can be controlled within the most stringent limit by air pollution abatement equipment. - Incineration can completely destroy micro-organisms.
Control and Enforcement	<ul style="list-style-type: none"> - Enforcement protocol is yet to be developed in other countries, e.g. no policy yet devised in the Environment Agency in UK. - There are also no agreed International Standards. 	<ul style="list-style-type: none"> - International Standards have already been set for reference (e.g. the European Union Directive on the Incineration of Waste and the USEPA Standards for gas emission controls). Air emission control systems are well proven.
The Clinical Waste Control Scheme	<ul style="list-style-type: none"> - Different treatment technologies would need to comply with different sets of operational requirements. The enforcement authority would need to assess individual technologies. This would take longer time and more resources to implement the control scheme. - If each hospital and clinics were to install their own facilities, the resource of implementing the control scheme (enforcement) would be quite significant. 	<ul style="list-style-type: none"> - This would offer the fastest and most practical route to implement the proposed clinical waste control scheme. - As there will be only one disposal facility in HK, the cost of enforcement would be smaller than several facilities scattering around the territory.

Local Factors Being Considered	ALTERNATIVE TECHNOLOGIES (autoclaves, microwaves, chemical treatment)	INCINERATION AT HK CWTC
Siting Issues	<ul style="list-style-type: none"> - No other site has been approved yet. - Planning permission would be required and due to public perception, proposal to build a waste facility in any other region is likely to run into opposition by the local community due to NIMBY effect. - If located in a hospital, the proposal could be opposed by the hospital staff or their families residing within the hospital. 	<ul style="list-style-type: none"> - Already in use as an operating plant and only requires modification of the plant. - Opposed by NGO's and the local residents due to the perception of risk.
Capital and Operational Costs	<ul style="list-style-type: none"> - Capital costs for the alternative and novel technologies vary widely. - A specification would need to be written and tenders would need to be sought to arrive at a true capital cost. As an indication (see para. 7.5.8) the basic capital cost of the equipment for a small scale pilot (500 tonne per annum) plant is in the order of HK \$2m (N.B. this figure is only for package plant and its installation and commissioning of the equipment). Operational costs are likely to be slightly more than incineration. 	<ul style="list-style-type: none"> - Modifications estimated to cost \$HK 52 million. This cost includes the reception facilities for private waste collection vehicles, weighing facilities for waste collection vehicles and transit skips, facilities for washing and disinfecting all transit skips delivered to CWTC by waste collectors, safety facilities, cold storage for human body parts, supplying all transit skips for all hospitals in HK. - No land cost is incurred as no additional land is needed
Availability of Other Facilities	<ul style="list-style-type: none"> - Autoclaves being used in hospitals to sterilize surgical equipment and dressings cannot be used to treat clinical waste because VOCs and heavy metals emitted during autoclaving clinical waste will contaminate the inside wall of the autoclaves and contaminate the surgical equipment if the autoclave is subsequently used to sterilize them. - Some small autoclaves are being used for sterilization of small amounts of laboratory microbiological cultures and cannot handle large amount of other clinical wastes. They are also not provided with shredders. Other than these, there is no other facility. 	<ul style="list-style-type: none"> - CWTC already in place and only minor modification will be required.
Time of implementation	<ul style="list-style-type: none"> - Implementation would depend on finding available sites for the facilities, carrying out feasibility study and environmental impact assessment, further consulting the public on the proposal, building all the associated structures and supplies, and installing the treatment facilities and training the staff for the new technology. - Requirements for training of workers to use alternative technology are yet to be developed and agreed by the US STAATT. 	<ul style="list-style-type: none"> - No additional land or site will be required. The only time required will be for modification work. - Requirements for training operators of incinerators are well established and recognized.

7.4.8 All these point to the advantages of modifying the present incineration plant of CWTC for treating clinical waste. Hence, proceeding with the modification of the CWTC is the recommended medium-term option particularly due to the constraints of adopting alternative technology in HK:

- a) The time that will be necessary to find, and seek approval for alternative sites would be lengthy;
- b) The time that will be taken to develop alternative safe and environmentally acceptable systems and technology would be considerable;
- c) Space in hospitals in Hong Kong is at a premium. The installation of an in-house Alternative Technology Unit with all of the ancillary equipment and waste storage capacity would be very difficult to achieve without disruption to the other services in the hospital;
- d) It will always be difficult to obtain approval for new sites for the treatment and disposal of clinical waste due to the perceptions of risk (see para. 5.7);
- e) Land in Hong Kong is always at a premium; and
- f) The need to keep the present incineration facility fully operational to dispose of hazardous waste as well as disposing of those types of clinical waste that cannot be treated by the alternative technologies(see Table B).

7.4.9 As any facility, e.g. the CWTC, has a designated life-span, whilst it is recommended that the Hong Kong Government proceeds with the modification of CWTC, the Hong Kong Government should also carefully consider the following recommendations in the longer term:

- a) Keep abreast of the independent research being carried out worldwide and carry out a watching brief on the acceptance internationally of standards for efficacy testing, environmental testings and licensing criteria of alternative technologies.
- b) Keep abreast of developments in other novel technologies. Hong Kong should not be involved in any experimentation at this stage but rather the Government should hold a watching brief on the developments taking place worldwide.
- c) After obtaining more information on a) and b), to consider installing at a suitable site an Alternative Treatment Facility. A study should be carried out to decide on the purchasing, installation and operation of one technology, paying particular attention to the ease of operation and maintenance and the operational costs.

- d) Based on the findings of the Hospital Authority's report and the present report, it is suggested that an autoclave can be considered. The reasons are that:
- i. the technology is well known in hospitals,
 - ii. the technology is comparatively simple and more well developed and the capital costs are likely to be less than other more complex technologies, and
 - iii. the number of autoclaves being used in USA is greater than the number of other facilities.

It is suggested that the Hong Kong Government should not have all their eggs in one basket. Evaluation of autoclave technology should begin with one installation in the near future. The capital cost for 500 tonne per annum equipment is in the order of HK \$2m. This figure includes automatic loading and post-treatment shredding equipment. However, extra cost should be allowed for special air pollution control equipment. Likewise the capital cost given does not include the cost of land or civil engineering works that will be required.

7.4.10 It is recommended that in the medium term the Hong Kong Special Administrative Region should proceed with its proposed modification of the CWTC to treat clinical waste.

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Curricula Vitae of the Author and Assistant Authors

William King TOWNEND OBE. MPhil. F Inst WM. FIM.

Background, Vocational and Managerial Experience

His basic discipline is environmental health. Over the past 34 years he has been employed in an executive capacity in the waste management industry and during that period he has been able to obtain in depth experience of all aspects of the industry both as an operator and regulator. In 1986 following the abolition of the Greater London Council (GLC) he participated at a senior management level in the creation and development of a new organisation, the London Waste Regulation Authority (LWRA), which was dedicated to environmental protection and recognised both nationally and internationally as a "centre of excellence". When the LWRA was subsumed into the Environment Agency in April 1996, he was appointed the Senior Adviser in the Head Office Waste Management and Regulation Policy Group until he retired in February 1998. He is now an international environmental adviser and consultant and Non-Executive Chairman of Torgam Developments Ltd, an operational and consulting company specialising in healthcare waste management which he joined in August 1999.

He has obtained very wide ranging experience of the political and policy making processes at local, national and international level and has actively participated at all levels in policy development.

In April 1973 he was appointed an Officer by the GLC and for 8 years until it was abolished in 1986; he managed the Operations Division of the Waste Management Branch. The Division consisted of a large multidisciplinary team of managers, engineers, scientists, supervisors and administrators which together with the operative staff numbered over 500 with an annual budget of £110 million (2000 equivalent).

He was responsible for the operation of over 60 sites including the largest municipal Waste-to-Energy incineration plant in the U.K. at Edmonton. His responsibilities also covered the operation, completion and subsequent restoration of a number of large landfill sites. He was responsible for a complex network of transfer stations using road, rail and river transport. These services were provided by a wide range of direct labour and private sector organisations with short term and long term contracts which he was actively engaged in specifying, negotiating and managing.

Over the past 15 years, he has worked very closely with most Government Departments particularly the Departments of the Environment, Health, Trade and Industry, Agriculture Fisheries and Food, Transport, Home Office and also with most of the enforcement agencies. He also has had close working relationships with other international enforcement agencies and with the officials of DGXI of the European Commission.

He holds a Master of Philosophy Degree in Biology and is an Associate Reader at Brunel University. His other appointments include: -

- Joint Deputy Chairman of the Waste Management Industry Training and Advisory Board
- Member of the International Criminal Police Organisation (Interpol) Working Party on Environmental Crime and led the UK Delegation to the Conference in November 1997.
- He was the founder Chairman of the Interpol Environmental Crime Group (UK)

Experience in Healthcare Waste Management

The considerable national and international experience the author has obtained in Healthcare Waste Management is set out below:

- Chaired the London Waste Regulation Authority Clinical Waste Enquiry in London (CWEL) during 1987 to 1989 and produced Guidelines for clinical waste management being launched by the Government and adopted nationally. They remain the Environment Agency's policy document. Following on from that assignment he became the Chairman of the peer group that produced the last draft of the Governments Waste Management Paper No 25 commissioned by the Department of the Environment.
- As Head of Waste Management Operations in the GLC he was responsible for the commissioning and operation of the Edmonton Clinical Waste Incinerator.
- Adviser to the UK Audit Commission and assisted in the production of their appraisal of clinical waste management in the UK.
- He has acted as consultant and Adviser to the World Health Organisation (WHO) and other international aid agencies and has been involved in Healthcare waste assignments in Hungary (Two), Palestine, Jordan, Argentina, Portugal and Chile.
- Acted as the WHO representative on the European Commission's Priority Waste Stream Project on Health Care Waste.
- In 1996 he was instrumental in forming the International Solid Waste Association's (ISWA) Working Group on Health Care Waste and becoming it's Founder and current Chairman of the Working Group.
- Since 1979 he has produced 25 publications on healthcare waste management and presenting 15 of them at seminars or conferences.
- Joint author of the WHO Publication "Teacher's Guide - Management of wastes from health-care activities", Geneva 1998.

**Details of PROFESSOR JOHN D. DONALDSON BSc; PhD; FRSC, C. Chem; FRSA
Centre for Environmental Research, Brunel University, Uxbridge, United Kingdom**

Qualifications:

B. Sc University of Aberdeen
PhD University of Aberdeen
D.Sc. University of London

Professional Qualifications.:

Fellow of the Royal Society of Chemistry
Chartered Chemist
Fellow of the Royal Society of Arts

Experience:

John Donaldson is currently Professor in the Centre for Environmental Research in the Department of Materials Engineering at Brunel University. He has extensive experience in the management of both fundamental and industrial based research projects. His recent research has been concerned with problems of interest to industry and includes both fundamental and applied studies of environmental science topics. More than 100 research workers working under his supervision have obtained doctorate degrees and he has published over 200 papers in the scientific literature.

Professor Donaldson is Director of the Hopeman Associates Limited and has acted as a consultant and adviser to a large number of companies in the chemical, agricultural, food, water treatment, mineral treatment, heat exchanger, paint and electronics industries. He is currently advisor to the Bureau Internationale-do la Recuperation et du Recyclage on Technical Working Group issues related to the Basel Convention. Professor Donaldson has also advised legal, insurance and investment companies on environmental issues. He is currently Deputy Chairman of the Waste Management Industry Training and Advisory Board and a member of the Institution of Electrical Engineers Energy and the Environment Committee. Prior to moving to Brunel University in 1990 Professor Donaldson was for ten years Professor of Industrial Chemistry and Director of the Industrial and Biological Chemistry Research Centre at The City University in London. Professor Donaldson was the foundation appointee to the Chair of Industrial Chemistry and successfully carried out the dual tasks of setting up a research centre and forging three-way links between the University, the chemical and related industries in the City of London.

**Details of Dr SUE GRIMES BSc; PhD; MBA; MRSC, C.Chem.; Dip. MRS
Centre for Environmental Research, Brunel University, Uxbridge, United Kingdom**

Qualifications:

BSc University of London
PhD The City University, London
MBA The City University, London

Professional Qualifications:

Member of the Royal Society of Chemistry
Chartered Chemist
Diploma of the Market Research Society

Experience:

Sue Grimes' qualifications of a first class honours degree and a doctorate in Chemistry combined with an MBA, bringing a unique combination of skills to her environmental science research and consultancy work. She is currently head of the Centre for Environmental Research at Brunel University, Director of the Masters courses in Environmental Pollution Science, Environmental Science with Legislation & Management, Environmental Science with Occupational Health and Environmental Management. She has represented academia nationally on The Royal Society of Chemistry's working party for the accreditation of environmental auditors, verifiers and assessors.

Sue is an experienced research supervisor of academic and industrial-based projects in inorganic, industrial and environmental chemistry. She has built up a research group at Brunel which carries out studies on fundamental aspects of environmental sciences. The group which already consists of three post-doctoral workers and more than twenty researchers has attracted considerable support from industry. She has published about 100 papers in the scientific literature. Dr Grimes has acted for fifteen years as a consultant to water treatment companies and has carried out research for, or advised other organisations in the automobile, chemical, effluent treatment, food, heat exchanger, hydro-metallurgical, metal recovery, paints, petroleum and textile industries. She has been a senior managing consultant in projects involving contaminated land, effluent treatment and control, water treatment, control of atmospheric emissions, environmental impact audits and environmental legislative compliance. She is also Technical Editor for SCI's Journal of Chemical Technology and Biotechnology. Prior to moving to Brunel University in 1990, Dr Grimes was a lecturer in chemistry at The City University. In her capacity as Tutor to a Masters degree in Industrial and Administrative Sciences she initiated and directed research projects in both industrial chemistry and technical management. The topics of the management studies included services marketing in technical industries, management of environmental problems in technical industries, managing creativity and research management.