WHO/SDE/WSH/04.07
English only

Findings on an Assessment of Small-scale Incinerators for Health-care Waste

S. Batterman

Water, Sanitation and Health
Protection of the Human Environment
World Health Organization
Geneva
2004

Findings of an Assessment of Small-scale Incinerators for Health-care Waste

Table of Contents

Figures

Tables

Abbreviations

TEQ - toxicity equivalent quantity

US EPA - United States environmental protection agency

WHO - world health organisation

SSI - small scale incinerators

PVC - polyvinyl chloride

PAH - polyclinic aromatic hydrocarbon

HCW - health-care waste

CEM - continuous emission monitoring

PIC - product of incomplete combustion

POPs - persistent organic pollutants

HRA - health risk assessment

NRC - national research council

TDI - tolerable daily intake

PTMI - provisional tolerable monthly intake

MOE - margin of exposure

LOAEL - lowest observed adverse effect levels

MWI - medical waste incinerators

PCDD - polychlorinated dibenzo-para-dioxin

PCDF - polychlorinated dibenzofuran

PCB - polychlorinated biphenyl

UNEP - united nations environment programme

HCWH - health-care without harm

UNDP - united nation development programme

2,3,7,8-TCDD - tetrachlorodibenzo-para-dioxin

MEI - maximum exposed individual

EU - European Union

IARC - international agency for research on cancer

Summary

This report provides an analysis of low cost small-scale incinerators used to dispose of health-care waste in developing countries, specifically sharps waste (used and possibly infected syringes and needles). The report includes a situation analysis, a "best practices" guide to small-scale incineration, a screening level health risk assessment for ingestion and inhalation exposure to dioxin-like compounds, and other information related to the operation and evaluation of the incineration option for health-care waste.

The situation analysis documents the need for adequate and safe disposal. Quantities of sharps waste generated monthly range from a few kg at remote clinics, to hundreds or possibly thousands of kg at central hospitals, to approximately 1 000 tons world-wide during vaccination campaigns. With improper disposal, syringes and needles may be scavenged and reused, leading to large numbers of people becoming infected with hepatitis, AIDS and other diseases. To avoid these serious health problems, international agencies have promoted the use of low-cost small-scale incinerators. The more recent versions of simple brick incinerators, e.g., the De Montfort Mark8A, utilize primary and secondary combustion chambers, some basic operator safeguards, and a short chimney. These units are built on-site for several hundred to US$ 2 000, depending on the availability of materials and metal working facilities. The use, maintenance and management of these incinerators has been evaluated in four countries using survey-based rapid assessment techniques, and combustion parameters (temperatures, flows, etc.) and emissions (carbon monoxide, dioxins, etc.) have been measured in several field tests. The surveys show widespread deficiencies in the construction, siting, operation and management of these units. These deficiencies can result in poor performance of the incinerator, e.g., low temperatures, incomplete waste destruction, inappropriate ash disposal, high smoke emissions, fugitive emissions, etc. Still, user acceptance of small-scale incinerators appears generally high and the use of incinerators is preferable to the disposal of waste in unsecured pits or landfills, or (uncontrolled) burning in drums or pits. However, the combustion of health-care waste can form particulate matter, dioxins, furans and other toxic air pollutants.

Emission standards for modern incinerators require the use of various air pollution control devices as well as monitoring, inspection and permitting programs. Such standards cannot be met by small-scale incinerators that do not incorporate any air pollution control devices or monitoring devices. Moreover, as typically operated, small-scale incinerators do not achieve the lowest possible emissions. Installation of process monitors, emission controls, and other equipment necessary to meet modern emission standards would increase costs by at least an order of magnitude. When incinerators are used, however, "best practices" should be promoted to minimize occupational and public health risks.

"Best practices" for small-scale incineration has goals of suitably treating and disposing of waste, minimizing emissions, and reducing occupational exposures and other hazards. Best practices includes the following elements: (1) Effective *waste reduction* and *waste segregation*, ensuring that only the smallest quantity of appropriate waste types is incinerated. (2) An engineered *design*, ensuring that combustion conditions are appropriate, e.g., sufficient residence time and temperatures to minimize products of incomplete combustion. (3) *Siting* incinerators away from populated areas or where food is grown, thus minimizing exposures and risks. (4) *Construction* following detailed dimensional plans, thus avoiding flaws that can lead to incomplete destruction of waste, higher emissions, and premature failures of the incinerator. (5) Proper *operation*, critical to achieving the desired combustion conditions and emissions, e.g., appropriate start-up and cool-down procedures; achievement and maintenance of a minimum temperature before waste is burned, use of appropriate loading/charging rates (both fuel and waste) to maintain appropriate temperatures, properly disposal of ash, and various actions and equipment to safeguard workers. (6) Periodic *maintenance* to replace or repair defective components, e.g., including inspection, spare parts inventory, record keeping, etc. (7) Enhanced *training and management*, possibly promoted by certification and inspection programs for operators, the availability of an operating and maintenance manual, management oversight, and maintenance programs.

Public health risks from incinerator emissions are driven largely by dioxin and furan emissions. For these toxic, persistent and bioaccumulative chemicals, analyses must consider inhalation and ingestion exposures, the latter due to the consumption of locally-produced foods that become contaminated. Information related to hazard assessment, dose response, exposure assessment, and risk characterization for dioxin-like compounds is reviewed. Several parameters necessary to quantify exposures and risks have considerable uncertainty and high site-to-site variability, thus risk modeling utilizes a range of scenarios and sensitivity analyses. Information related to the emissions of dioxin-like compounds from incinerators without emission controls is reviewed, and three classes are considered: (1) *Best practice* for a properly operated and maintained unit utilizing sufficient temperatures, afterburners and other features that limit chimney (stack) concentrations to 10 ng TEQ/Nm^3; (2) *Expected practice* for an improperly designed, constructed, operated or maintained units, giving a 500 ng TEQ/Nm^3 limit; (3) *Worst-case* using an incinerator without an afterburner, giving a 4000 ng TEQ/Nm^3 concentration. To reflect a range of settings and conditions, four incinerator usage rates were considered: (1) Low usage, equivalent to 1 hr of incineration or 12 kg waste per month; (2) Medium usage, 2 hr or 24 kg waste per week; (3) High usage, 2 hr or 24 kg per day; and (4) Universal usage – burning 12 000 to 20 000 tons per year, equivalent to sharps waste from vaccinations throughout the developing world. Uptake rates for adults and children due to food consumption were estimated by coupling emission and usage rates to estimates of individual intake fractions based on recent studies in the US and Europe. Worst-case inhalation exposures for adults and children were estimated using a plume dispersion model, a range of meteorological conditions, and the same emission conditions discussed above. This modeling also showed the effect of stack (chimney) height on exposures. The resulting uptake rates were compared to WHO's provisional tolerable intake rate, US EPA's cancer risk levels, and other indicators. Because of significant uncertainties, e.g., current exposures are unknown, it is prudent to keep exposures from small-scale incinerators to a small fraction of the provisional value.

Dioxin/furan emissions from a single small-scale incinerator that is operated infrequently under best practices is not likely to produce excessive ingestion exposures and risks, however, the feasibility of achieving and sustaining best practices seems doubtful. Under the expected practices emissions, only the low usage scenario keeps the intake to a small fraction of the WHO provisional intake. Ingestion intake rates and risks are unacceptable for the worst-case emission rate at any usage rate. Widespread use of incinerators gives similar exposures and risks similar to that obtained for a single unit, e.g., exposures are below 1% of the provisional WHO value, and aggregate emissions are 1 to 2 g TEQ/year. Under actual practices to worst-case emissions, adult exposures range from 1 to 12% of the WHO provisional value, exposures to children are 17 times higher, and between 60 and 800 g TEQ/year are emitted, a significant fraction of continental and global emissions. Only with best practices are exposures and risks small. The plume modeling shows that maximum airborne concentrations occur at downwind distances from 0 to 800 m, with distances increasing under stable conditions. During the day (neutral and unstable conditions), maximum concentrations occur very close to the incinerator (within 100 m). Increasing stack height from 3 to 6 m significantly lowers concentrations by 5 to 13 times during daytime, and the major effect is observed close to the source (especially relevant for operator exposure). Dilution ratios of at least 1000 are desirable. Ratios well below 1000 can occur at distances below 100 m for daytime conditions, regardless of stack height. At night, ratios below 1000 occur only with the shortest stack height (3 m) and for distances from 200 to 500 m. Low and medium usages under best practices emissions give exposures below 1% of the provisional WHO limit. Like the ingestion estimates, the inhalation assessment has many uncertainties, data gaps are large, and consequently the calculated exposures and risks reflect a wide range. Moreover, results are applicable to open sites where dispersion is not inhibited, and not to incinerators sited in forests or mountainous terrain.

In conclusion, small-scale incineration is viewed as a transitional means of disposal for health-care waste. The analysis in this report shows significant problems regarding the siting, operation, maintenance and management of incinerators. While uncertainties are high, emissions of toxic and persistent compounds from incinerators may result in human exposure at levels associated with adverse health risks. Because chronic exposures to dioxins/furans are judged to pose the major public health risk, transitioning to safer options over a period of several years would not be expected to result in significant adverse consequences, especially if most elements of best practices are followed.

1 Introduction

1.1 Objectives

This report is aimed providing information and analyses for the following objectives:

1. Developing best management practices for small-scale medical waste incinerators. *What can be done to improve operations and reduce risks?*
2. Updating risk evaluations of toxic emissions from small-scale incinerators, specifically addressing dioxin and furan[1] emissions resulting from the incineration of sharps (syringes and needles). *What are the risks from small-scale incinerators?*
3. Providing background and justification for the development and implementation of acceptable emission limits for small-scale incinerators. *Can the principle of risk-based regulatory controls be adapted to small-scale incinerators?*
4. Developing incinerator emission limits and a compliance schedule that minimize risks. *How should risks from incineration be controlled?*
5. To discuss non-incineration treatment options and provide information to help countries promote environmentally safer options for health-care waste treatment. *Where do we go from here?*

1.2 Approach

The approach taken to complete the stated objectives is to (1) understand the science and practice of medical waste incineration; (2) to describe risks and specifically the emission sources and pathways that lead to exposure; and (3) to quantitatively assess risks and other key outcomes using models. At the onset it should be recognized that the information available to assess small-scale incinerators and other treatment technologies is extremely limited. This report utilizes available information, and best attempts are made to discuss and in cases to estimate uncertainties.

Feedback. The author welcomes comments and suggestions, including additional data and experiences that might be incorporated. Requests to obtain additional information included a brochure soliciting input distributed in Africa (Appendix A).[2]

Scope. The analysis is largely limited to analysis of small-scale incinerators and other treatment options suitable in poor rural areas that have limited options for health-care waste disposal. This imposes several limitations:

- Incinerator type: Only small units (e.g., <12 to 100 kg/waste per hour), either batch-type designs (waste loaded before combustion and the ash removed after cool-down) or intermittent-type designs (continuous or periodic feeding of waste, ash removal after cool-down), are considered.
- Pollution controls: To limit emissions, small-scale incinerators generally employ several combustion controls and techniques. Other controls, e.g., flue gas treatment by wet or dry scrubbing, particulate filtration, etc., are rarely if ever employed due to cost and complexity.
- Lack of on-site/local infrastructure: In many or most settings, individuals and infrastructure necessary to provide commissioning, inspection, permitting, emission monitoring, operator certification, will be unavailable.

---

[1] Throughout this report, "dioxins and furans" means all polychlorinated dibenzo-p-dioxins and dibenzofurans, which are evaluated in terms of toxic equivalents.

[2] Several responses have been obtained from S. Africa and Zambia.

2 Situation analysis regarding health-care waste

2.1 Overview

2.1.1 Generation and disposal of health-care waste

Developing countries have had extremely limited options for safe waste disposal, especially for used and/or contaminated sharps (lancets, blades, syringes or hypodermic needles with or without attached tubing; broken glass items such as Pasteur pipettes and blood vials, and other invasive devices) that can cause injury and that are associated with significant risk of infection if indiscriminately disposed. (Infectious waste[3] can also include non-sharps, e.g., materials that have been in contact with blood, its derivatives, or other body fluids, e.g., bandages, swabs or items soaked with blood.) While generally less than 10% of health-care waste is considered infectious, many countries have poorly developed waste segregation practices. This complicates waste management since commingling sharps and other infectious waste with non-infectious waste will increase the amount of waste considered infectious that requires special treatment for safe treatment and disposal.

Resources are extremely limited in many countries, especially in remote areas. Consequently, open pit burning is still widely practiced for health-care waste including sharps, though this practice is objectionable due to emissions, the incomplete disinfection and destruction of the waste, and community complaints.

The volume of health-care waste varies by the size and activity of the clinic/hospital/provider. Small rural clinics may generate relatively small quantities of infectious waste, e.g., 1 to 10 kg of sharps per month. Quantities can be orders of magnitude greater at large urban clinics and hospitals. Quantities can greatly increase during immunization campaigns, e.g., the 2001 measles mass immunization campaign in West Africa (covering all or part of six countries) vaccinated 17 million children and generated nearly 300 tons of injection-related waste (Kezaala 2002). Throughout the developing world, WHO estimates that routine immunizations of children under one year and immunization of women of childbearing age with tetanus toxoid accounted for over one billion injections in 1998, while measles control/elimination activities and disease-outbreak control operations accounted for another 200 million injections in the same year (WHO 1999). These 1.2 billion injections are

---

[3] WHO provides the following definition of infectious waste: Infectious waste is suspected to contain pathogens (bacteria, viruses, parasites, or fungi) in sufficient concentration or quantity to cause disease in susceptible hosts. This category includes:

- Cultures and stocks of infectious agents from laboratory work;
- Sharps - items that could cause cuts or puncture wounds, including needles, hypodermic needles, scalpel and other blades, knives, infusion sets, saws, broken glass, and nails. Whether or not they are infected, such items are usually considered as highly hazardous health-care waste.
- Waste from surgery and autopsies on patients with infectious diseases (e.g. tissues, and materials or equipment that have been in contact with blood or other body fluids);
- Pathological waste consists of tissues, organs, body parts, human fetuses and animal carcasses, blood, and body fluids. Within this category, recognizable human or animal body parts are also called anatomical waste. This category should be considered as a subcategory of infectious waste, even though it may also include healthy body parts; • waste from infected patients in isolation wards (e.g. excreta, dressings from infected or surgical wounds, clothes heavily soiled with human blood or other body fluids);
- Waste that has been in contact with infected patients undergoing haemodialysis (e.g. dialysis equipment such as tubing and filters, disposable towels, gowns, aprons, gloves, and laboratory coats);
- Infected animals from laboratories;
- Any other instruments or materials that have been in contact with infected persons or animals.

estimated to produce 12 000 to 20 000 tons of infectious waste.[4] Additional immunizations are anticipated as new vaccines appear and for the poorest countries where vaccines are needed most. Safe waste disposal options are needed to deal with these quantities, as well as the wastes generated by routine health-care provision.

2.1.2 Risks of infection

Improper disposal of health-care wastes, syringes and needles that are scavenged and reused may lead to significant numbers of hepatitis B, hepatitis C, HIV and possibly other infections in the developing world (Simonsen 1999). In some countries (e.g., India and Pakistan), contaminated disposable needles are often scavenged, repackaged, sold and reused without sterilization. Such practices are associated with serious health implications due to the transmission of infectious disease, especially hepatitis and AIDS. Several populations are at risk from poorly managed health-care waste:

- Health workers.
- Waste handlers.
- Scavengers retrieving items from dumpsites.
- People receiving injections with previously used needles/syringes.
- Children who may come into contact with contaminated waste and play with used needles and syringes, e.g., if waste is dumped in areas without restricted access.

Based on data taken from health-care settings, a person receiving one needle stick injury from a contaminated sharp used on an infected patient has a probability of 30%, 1.8% and 0.3% of being infected by Hepatitis B, Hepatitis C and HIV, respectively (Seeff et al. 1978; CDC 1997; Simonson et al. 1999). Globally, Hauri et al. (2004) estimates that the re-use of non-sterile syringes causes 21 million hepatitis B infections (32% of new cases) per year, 2 million hepatitis C infections (40% of new cases) per year, and 260,000 HIV infections (5% of new cases) per year. Other illnesses possibly transmitted by non-sterile syringes include ebola and lassa fevers, malaria, and wound abscesses (Simonsen et al. 1999). Miller and Pisani (1999) estimate 1.3 million deaths per year due to infections transmitted from contaminated injection equipment, while Hauri et al (2004) estimated that there were 501,000 deaths in 2000 due to unsafe injections in health-care settings.

[4] The low estimates is based on a safety box weighing about 1 kg when full of 100 syringes with needles. Associated waste will include gloves, swabs, etc. The high estimate is scaled from Keezala's (2002) estimate.

Health-care waste treatment options

The many available waste treatment options for health-care waste treatment may be classified into four processes: thermal (including incineration), chemical (using disinfectants), irradiative (using ionizing ration), and biological (using enzymes). These processes are generally used in conjunction with mechanical shredding, compaction and mixing to render waste unrecognizable, to improve heat or mass transfer, and/or to reduce the volume of treated waste. Reviews of health-care waste treatment options are provided elsewhere (Prüss 1999; HCWH 2001).

The selection of appropriate treatment options depends on many factors including (HCWH 2001):

- throughput capacity
- types of waste treated
- microbial inactivation efficacy
- environmental emissions and waste residues
- regulatory acceptance
- space requirements
- utility and other installation requirements
- waste reduction
- occupational safety and health
- noise
- odor
- automation
- reliability
- level of commercialization
- background of the technology manufacturer or vendor
- costs (both initial and operating)
- community and staff acceptance

HCWH (2001) and others point out that no one technology is a panacea to the problem of health-care waste, and that each technology has its advantages and disadvantages.

2.2 Evaluating technological options

The various technologies should be evaluated using comparable health, environmental and economic criteria. Often, this is difficult given uncertainties but it is possible to describe possible risks, benefits and costs. Importantly, the feasibility and desirability of most waste treatment options will likely depend on waste volumes currently generated and trends for the near-term (say 5 years). In their evaluation, waste generators ideally should undertake a waste audit, formulate appropriate indicators to assess and forecast waste generation trends (e.g., waste generated per type of procedure), and assume moderate-to-intensive efforts to minimize waste (depending on current minimization efforts).

The following criteria are suggested in evaluating small-scale treatment options for health-care waste:

- Effectiveness: Wastes should be completely sterilized and rendered into a form that prevents hazards or reuse.
- Cost-effectiveness: The technology should be economically competitive with other available options. A life-cycle cost basis that accounts for all costs, e.g., capital, operating, training, regulatory, energy, liability, waste disposal, etc.
- Safety: The construction, operation, and closure of the technology/facility should not present unacceptable environmental or human health risks. This includes consideration of occupational, community and environmental risks resulting from any air emissions, water effluents, and solid wastes generated.

- Simple: Small-scale technologies for poor countries should ideally be easy to manufacture, operate and maintain.
- Robust: The technology should consistently meet air emission and other health and safety criteria under a wide variety of operating conditions.

WHO has a larger list of factors to guide the choice of treatment system, noting that many of them depend on local conditions list of criteria (Prüss 1999):

- disinfection efficiency
- health and environmental considerations
- volume and mass reduction
- occupational health and safety considerations
- quantity of wastes for treatment and disposal/capacity of the system
- types of waste for treatment and disposal
- infrastructure requirements
- locally available treatment options and technologies
- options available for final disposal
- training requirements for operation of the method
- operation and maintenance considerations
- available space
- location and surroundings of the treatment site and disposal facility
- investment and operating costs
- public acceptability
- regulatory requirements

2.3 Incineration of health-care waste

Incineration has been used for many years (see review by Lee and Huffman, 1996). Incineration can destroy or inactive infectious waste, provide significant (>90%) mass and volume reduction of the waste, and render materials (syringes, etc.) unusable. In developed countries, recent regulatory initiatives have significantly changed the utilization, design and operation of incinerators (see Section 5.8). In developing countries, controlled air incineration using low cost engineered small-scale facilities has been promoted by national governments and UNICEF and is currently used in a number of countries, often with external support. Small-scale incinerators may be built on-site, locally constructed, fixed and/or portable. Units typically operate for 1 to 6 hours per week or month in a batch or intermittent mode to destroy sharps and other health-care waste. For example, the brick incinerators, designed at De Montfort University by JD Pickens, have been introduced into both remote and urban areas in several countries, e.g., West and East Africa, Kosovo, Sri Lanka, etc. When new and appropriately operated and maintained, these high thermal capacity incinerators can achieve relatively high operating temperatures (700 to 800 C), largely destroying the waste and helping to reduce production and emissions of dioxins and furans in stack gases and ash. These incinerators are far preferable to waste burning in open pits or in steel drums, and user acceptance appears generally high. As discussed below, however, these incinerators are not performing optimally due to significant operation, maintenance and management issues.

There is a need to assess the risks attributable to toxic emissions of small-scale incinerators, to effectively communicate these risks to managers and policy makers involved with health-care waste management, and to document "best practices" to minimize risks should incinerators be used.

2.3.1 Risks from incineration emissions

Incinerator discharges (including disinfectants and pollutants) occur to air, water and soil. These discharges can lead to occupational and environmental exposures to toxic chemicals and subsequent health risks affecting waste workers, the general public, and the environment. With poor management, infectious risks may also remain, largely in the occupational setting, e.g., waste handlers and incinerator operators.

Health-care waste is a heterogeneous mixture that often contains chlorine (from materials containing polyvinyl chloride and other plastics), heavy metals (from broken thermometers), cytotoxins, radioactive diagnostic materials, infectious materials, pathogens, etc.[5] In consequence, incinerator emissions include both "conventional" pollutants, e.g., particulate matter, sulfur oxides, nitrogen oxides, volatile organic compounds and carbon monoxide, as well as dioxins, furans, arsenic, lead, cadmium, chromium, mercury, and hydrochloric acid. In the aggregate, incinerators can emit significant quantities of gaseous and particulate pollutants to the atmosphere (EPA 1996), and incineration of health-care waste in small and poorly controlled incinerators is a major source of dioxins and furans (UNEP 1999). Small-scale incinerators generally operate without pollutant controls. Additionally, other design, operation and maintenance issues produce much higher concentrations in stack gases than acceptable in modern and well-controlled incinerators.

Much of the concern regarding incinerator emissions concerns dioxins and furans.[6] General conditions necessary for dioxin formation include the presence of fly ash, organic or inorganic chlorine, metal ions and, ideally, a temperature range of 250 - 450 C (Huang 1996). Combustion of sharps alone in small-scale incinerators does not remove all chlorine from the waste stream and prevent dioxin formation since the polyvinylchloride (PVC) seal between the metal needle and the polyethylene body chlorine and the rubber plunger (piston) head of the syringe may contain chlorine (Oka 2002). (The syringe barrel and most of the piston are polyethylene, which does not contain chlorine, and which can be recycled.)

To date, most concern has focused on air emissions. Locally, incinerator workers and individuals living or working nearby can be exposed directly through inhalation, the so-called 'direct' exposure pathway. Additionally, air pollutants deposited in soil, vegetation and water can lead to so-called 'indirect' exposures through ingestion of locally-produced foods or water, and dermal absorption due to contact with contaminated dusts, soil, water, etc. For many contaminants, indirect exposures can far exceed direct (inhalation) exposures. Regionally (at some distance from incinerators), individuals are exposed through a different mix of pathways for persistent and/or bioaccumulative pollutants, e.g., polycyclic aromatic hydrocarbons (PAHs), dioxins, furans, polychlorinated biphenyls, mercury, chromium, cadmium, etc., that undergo chemical and physical transformations, cycling in and out of soil, vegetation, and surface water. At regional scales, most exposure is believed to occur through ingestion of food and water, and incidental soil and house dust).

The waste stream from incinerators also includes solid and liquid wastes, namely, bottom ash and residues from pollution control equipment (if any). Typically, solid wastes are disposed in soils (typically landfills or pits). Liquid wastes (e.g., wet scrubber effluent, boiler blow-down, etc.) from some incinerators may be further treated and discharged to a sanitary sewer. (No specific information on liquid waste releases for small-scale incinerators was found, though these processes are rarely employed.) Disposal of waste, ash, liquid or other residues in unlined pits or other improperly managed facilities may contaminate groundwater, which may be used for drinking water.

2.3.2 Incinerator performance

The more recent designs for low-cost small-scale incinerators promise effective sterilization of health-care waste, and these units have been constructed in a variety of settings. However, several studies using "rapid assessment techniques" indicate a variety of problems including operator training, management and supervisor support, operation and maintenance, and siting (see Figures 1 - 3):

---

[5] Cytotoxic, radioactive, and mercury-containing wastes should not be incinerated.

[6] In this report, dioxins and furans refers to all polychlorinated dibenzo-p-dioxins and dibenzofurans considered toxic, namely, the 17 congeners chlorinated in the 2,3,7 and 8 positions.

Figure 1 Photos indicating operational/training problems with De Montfort type incinerators.
Left: Incinerator operator wearing motorcycle helmet instead of respiratory protective gear (Mac Robert Hospital, Gurdaspur, Punjab, October 2002, taken from HCWH, 2002). Center: General waste to be burned (Kulathummel Salvation Army Hospital, Thiruva Nanthapuram, Kerala, Sept. 2002, taken from HCWH, 2002). Right: Black smoke indicating high pollutant emissions (WHO presentation, Bradley Hersh, location and date unknown, taken from HCWH, 2002)

Figure 2 Photos indicating construction problems for De Montfort Incinerators in Kenya.
All from Taylor (2003). Left: Front door frame damaged and also off-set inside making cleaning difficult. Right: Loading door frame rusted and hinge broken.

Figure 3 Photos indicating maintenance problems for De Montfort Incinerators in Kenya.
All from Taylor (2003). Left: Front door hinges damaged and frame dislodged from mortar. Right: Damaged masonry and loose fire-bricks

- Kenya: Some 44 De Montfort type incinerators were constructed in 2002, of which 55% are in intermittent or regular use. Tests and interviews were conducted at 14 sites (Adama 2003). Only 1 of 14 sites had an operator with ‘near to adequate’ skills, fewer than 40% of health facility managers demonstrated any level of commitment, many technical defects were observed in the equipment, and most incinerators were operated improperly (Taylor 2003).
- Tanzania: A total of 13 De Montfort incinerators were constructed in 2001 and 2003, and all were in use. Of these, <40% had trained operators, 70% had low smoke disturbance, and 60% have safe ash disposal (Adama 2003).
- Burkina Faso. Where utilized, equipment was poorly operated and under-utilized, i.e., the expected number of syringes incinerated fell short by about two-thirds (Adama 2003).
- India. Eight 1 to 2 year-old De Montfort incinerators at hospitals in India were surveyed by HCWH (2002). This survey indicated visible smoke from the stack; smoke emission from the chamber door and air inlets; commingling of sharps and non-infectious waste, despite some source segregation; large quantities of unburned materials (sometimes plastics, syringes, glass, paper and gauze) in the ash; deficient ash disposal practices; siting in all cases near populated areas (e.g., playground, orphanage, hospital staff quarters, a primary school, town center), and a lack of operator training.

Due to modest sample sizes and unknown inclusion criteria, these surveys may not provide the true frequency of these problems. However, the results of the surveys in the four countries are remarkably consistent and indicate significant technical, operational, maintenance and management shortcomings. Adama (2003) and Taylor (2003) state several key problems:

- No formal health-care waste infrastructure, e.g., lack of clear directives, inadequate definition of responsibilities, no waste management budget, sporadic controls, inadequate maintenance, dispersed training.
- Unclear ownership of incinerator, e.g., whose property and whose responsibility.
- Low skills and motivation of personnel, e.g., assignments to incineration tasks are casual, personnel are unskilled laborers, and assignments are short term (no more than 3 to 6 months).

2.3.3 Control of incinerator emissions

Incinerator emissions and associated risks may be reduced using by implementing emission standards, operational controls, and enhanced management practices. (These ‘best practices’ are discussed later in this report.) Emission rates (and exposures) from current small-scale incinerators are highly variable (see Figure 4) and may be high for a number of reasons:

- Incorrect construction of the incinerator.
- Incorrect operation, in part associated with operator’s lack of training.
- Poor combustion, e.g., low temperatures (<800 C) and short residence times (well below 1 second).[7]
- Lack of process monitoring. Visual cues are sometimes used, but temperatures and other parameters are not directly monitored.
- Inadequate maintenance.
- Absence of pollution controls. Existing units generally have no pollution controls.

---

[7] Small-scale incinerators are manually charged with fuel and waste at the operator’s discretion. Charging practices greatly affect temperatures, residence times, entrainment of ash, etc. For example, the De Montfort design appears to operate optimally at a charging rate of one safety box every 10 min (about 6 kg waste/hour) [personal communication, DJ Pickens, Dec. 15 2003]. Higher charging rates may overheat the system, causing the stack to glow red, increasing draft, decreasing residence, and increasing emissions.

Figure 4 Photographic examples of smoke emissions. All taken from Taylor (2003).
Left: Dark and dense smoke with excessive particulate matter emissions. Right: Low or almost no smoke emissions.

- Insufficient waste segregation and waste minimization. Waste segregation practices are generally deficient.
- Lack of emission limits, process and emission monitoring, inspection, etc.

Correcting these deficiencies can reduce emissions, with a commensurate reduction in risks.

As mentioned earlier, exposure to incinerator emissions has the potential to cause various health effects, both chronic (e.g., cancer) and acute (e.g., systemic toxicity) risks. In general, most health concerns are raised by emissions of particulate matter, heavy metals, dioxins, furans, and sometimes hydrogen chloride (Chen et al. 2001; Ficarella and Laforgia 2000; Cudhay and Helsel 2000).

2.3.4 Incinerator costs

Locally built small-scale incinerators like the De Montfort design cost about $1 500 to $2 000 USD to construct, plus costs of shelter, ash pit, etc. Construction costs depend on a number of factors, especially the availability and cost of refractory bricks, metal and metal-working facilities. Operational costs depend on utilization, but costs have been estimated to range from $1.8 to $8.8 USD per kg of waste for units handling 250 and 15 safety boxes per month, respectively (Taylor 2003). This cost analysis is presented, with minor modifications, in the left-most columns in Table 1. The right-hand side of the table provides cost estimates with enhanced training, management, oversight and maintenance, and several additional and required costs are incorporated. These enhancements increase costs in the low use scenario by 37% to about $12 USD per kg waste, and in the high use scenario by 13% to $2.7 USD per kg waste.

The cost estimates in Table 1 are preliminary and based on incomplete information. It should be noted that replacement metal parts constitute ~60% of initial construction costs, of which the chimney represents 30 – 50%. 160 bricks required are estimated to cost $208 USD (Taylor 2003).

Appendix B describes several small-scale incinerators, including costs.

Table 1 Costs of De Montfort type incinerators under two usage scenarios with and without enhanced operation.
Low use based on 15 safety boxes burned per month. High use based on 250 safety boxes burned per month, and weekly burnings. Current conditions based in part on Taylor (2003) and HCWH (2002). Initial construction costs estimated to range from $1 530 to $2 000 USD (higher value selected below). Changes in enhanced analysis are shown in bold.

		Current Conditions				***Enhanced Operation,Training, Maintenance***			
		Low Use Scenario		***High Use Scenario***		***Low Use Scenario***		***High Use Scenario***	
Category	***Unit rate***	***Unit price or quantity***	***Annual Cost***	***Unit price or quantity***	***Annual Cost***	***Unit price or quantity***	***Annual Cost***	***Unit price or quantity***	***Annual Cost***
Waste	Weight waste per box (kg)	0.75		0.75		0.75		0.75	
Burned	No. safety boxes per burn	15		50		15		50	
	Burns per year	12		52		12		52	
	Total weight burned (kg/yr)		135.00		1950.00		135.00		1950.00
Initial	MWI construction cost ($)	2000.00		2000.00		2000.00		2000.00	
Costs	Shelter, Pit, etc. cost ($)					**300.00**		**500.00**	
	Lifetime (year)	3.00		3.00		3.00		3.00	
	Interest rate (%/year)	4.50		4.50		4.50		4.50	
	Annualized cost ($/yr)		727.55		727.55		**836.68**		**909.43**
Operating	Person hours (hr/burn)	2.00		6.50		**3.00**		**7.50**	
Costs	Labor cost ($/hr)	0.67		0.67		0.67		0.67	
	Total Labor cost ($/year)		16.00		225.33		**24.00**		**260.00**
	Fuel cost /burn (1L kerosene, $)	0.47		0.47		0.47		0.47	
	Solid fuel (3.5 kg/kg waste, $/kg)	0.07		0.07		0.07		0.07	
	Total fuel costs ($/yr)		14.86		157.98		14.86		157.98
	Cost of safety boxes ($)	1.33		1.33		1.33		1.33	
	Total safety box cost ($)		240.00		3466.67		**240.00**		**3466.67**
Maintenance	Percent of Capital costs (%)	10.00		10.00		**20.00**		**20.00**	
Costs	Maintenance cost ($/yr)		200.00		200.00		**460.00**		**500.00**
Training +	Operator training costs (24 hrs/year)					**16.00**		**16.00**	
Oversight	Inspections (1 hr 12 times/year)					**8.00**		**8.00**	
	Management and permitting (4 hr/year)					**40.00**		**40.00**	
	Total additional labor costs						**64.00**		**64.00**
Total annual cost ($/yr)			1198.40		4777.53		1639.54		5358.08
Cost per kg ($/kg waste)			8.88		2.45		12.14		2.75

2.4 Other options

A variety of non-incineration treatment and disposal technologies for health-care waste, including several low cost options, are available or under development. While the emphasis of this report is small-scale incineration, these other options should be compared to incineration using identical evaluative criteria.

Appropriate low cost treatment options for sharps and other infectious wastes have focused largely on burial, encapsulation and autoclaving (sterilization by steam and pressure). Shredding of waste and landfill disposal is required following autoclaving. In developed countries, many hospitals and other generators have moved away from incineration to autoclaving, responding to increasingly stringent emission controls, cost arguments, and public acceptance. Autoclaving has a number of advantages:

- The technology is simple and effective.
- Costs are low, and the process can be modularized allowing scaling and application to small to large waste generators.

- Medical institutions have experience with autoclaves, e.g., many hospitals have similar facilities in laboratory and/or central sterile supply departments.

Health-care waste options are described elsewhere (HCWH 2001; 2002; WHO 1999). HCWH (2003) and others have begun pilot testing several innovative treatment technologies at rural hospitals, including the collection of sharps waste from immunization campaigns using reusable metal containers, which are collected and transported for treatment in a small centralized autoclave-shredder system. Two winners in HCWH's recent contest included:

- Solar-powered autoclave-style sterilizer (Sydney University) in 1.5 and 14 L/batch versions.
- Boiling chamber with mechanical grinder and compactor (Newcastle upon Tyne Hospitals NHS Trust) in which bags of medical waste are placed into a grinding chamber, reduced to small particles that are then boiled by a firebox.

Other technologies under development include:

- Whole syringe melting/sterilization. Application of sufficient heat (>165 C) will melt syringes into a consolidated mass in which needles are embedded. This material may be recycled or disposed. Solar powered units may be feasible.[8]
- Enhanced recycling. Polyethylene is easily recycled, but the potential for recycling can be increased by several factors: more effective ways to disable the needle (rather than needle cutters); elimination of all metal from the syringe (including needle remnants and retaining clips); and elimination of non-polyethylene components (e.g., replacing current rubber plunger head with other elastomers).

At a recent WHO workshop (December 15, 2003), it was suggested that tenders for the development and demonstration of safe waste treatment options be solicited as part of – or prior to – major immunization campaigns. New technologies can be expected to undergo several cycles of testing and improvements, requiring a few years. Strong support, including financial, technical, management, outreach, communication and management, will hasten technology innovation, refinement, and adoption.

[8] IT Power India has a prototype solar powered melting system. Development work on another melting system is underway at the Georgia Institute of Technology. (Personal communications, T. Hart, Y. Chartier, Dec. 15, 2003; J. Colton, January 2004).

3 Best practices for incineration

This section discusses best practices for incineration, which can lead to substantial reductions in the formation, emission and exposure to toxic substances from waste incineration.

3.1 Waste reduction

Waste reduction reduces the volume and toxicity of materials for incineration (or other treatment option), thus decreasing incinerator use, emissions and the resulting health and environmental risks. For example, incineration might be reserved for only the most dangerous types of waste, e.g., contaminated sharps. Waste reduction can substantially lower demands for incineration and provide other important benefits, e.g., greater environmental protection, enhanced occupational safety and health, cost reductions, reduced liability, regulatory compliance, and improved community relations (HCWH 2001).

As mentioned, extensive reviews of waste reduction have been provided elsewhere (HCWH 2001; 2002; WHO 1999). General approaches include source reduction, material elimination, recycling, product substitution; technology or process change, use of good operating practices, and preferential purchasing. Hospitals and other facilities have many opportunities to minimize waste, including:

- Segregating wastes. This requires clearly marked and appropriate containers, staff training to separate various wastes (health-care waste, hazardous waste such as mercury, low-level radioactive waste, and regular trash), minor maintenance infrastructure (containers, suitable space) and management support.

  Studies in Nigeria and Benin show that health-care waste is either not segregated or insufficiently segregated (Adama 2003). The same study shows that policies and action plans are not sufficient or not comprehensive enough to address this problem.

- Reducing unnecessary injections (as much as 70% of all injections may be unnecessary) (Gumodoka et al., 1996).
- Recovering silver from photographic chemicals.
- Eliminating mercury products and mercury-containing instruments.
- Buying PVC-free plastic products.
- Treatments to remove and concentrate waste, e.g., filters and traps to remove mercury from wastewater.

Effective waste reduction programs require commitment of top management and effective communication among hospital staff. Physicians, other medical staff and managers must be made aware of waste generation and associated hazards. Source reduction requires involvement of purchasing staff and periodic reassessment. These programs require staff and moderate infrastructure support, planning and organization, assessment, feasibility analysis, implementation, training, and periodic evaluation. A waste audit will generally be helpful.

3.2 Design

Proper design and operation of incinerators should achieve desired temperatures, residence times, and other conditions necessary to destroy pathogens, minimize emissions, avoid clinker formation and slagging of the ash (in the primary chamber), avoid refractory damage destruction, and minimize fuel consumption. Good combustion practice (GCP) elements also should be followed to control dioxin and furan emissions (Brna and Kilgroe 1989). Table 2 provides recommendations for small-scale intermittent incinerators.

It appears that the temperature, residence time and other recommendations in Table 2 are rarely achieved by small-scale incinerators. Additionally, as mentioned earlier, few small-scale units utilize air pollution control equipment.

3.3 Siting

The location of an incinerator can significantly affect dispersion of the plume from the chimney, which in turn affects ambient concentrations, deposition and exposures to workers and the community. In addition to addressing the physical factors affecting dispersion, siting must also address issues of permissions/ownership, access, convenience, etc. Best practices siting has the goal of finding a location for the incinerator that minimizes potential risks to public health and the environment (EPA 1997). This can be achieved by:

- Minimizing ambient air concentrations and deposition of pollutants to soils, foods, and other surfaces, e.g.,
    - Open fields or hilltops without trees or tall vegetation are preferable. Siting within forested areas is not advisable as dispersion will be significantly impaired.
    - Valleys, areas near ridges, wooded areas should be avoided as these tend to channel winds and/or plumes tend to impinge on elevated surfaces or downwash under some conditions.
- Minimizing the number of people potentially exposed, e.g.,
    - Areas near the incinerator should not be populated, e.g., containing housing, athletic fields, markets or other areas where people congregate.
    - Areas near the incinerators should not be used for agriculture purposes, e.g., leafy crops, grasses or grains for animals.

Appropriate sizes for buffer surrounding incinerators are based on dispersion modeling (Section 6.4.5). For typical small-scale units, especially if nighttime operation may occur, a 500 to 750 m buffer surrounding the facility is advisable to achieve dilution ratios above 1000. During the day, a 250 m buffer should obtain the same dilution ratio. These distances are based on ideal conditions, e.g., relatively flat and unobstructed terrain.

Table 2 Recommendations of key design/operating parameters for small-scale intermittent incinerators.

Derived in part from EPA (1990), UNDP (2003), and De Montfort literature.

Type	***Parameter***	***Recommendation***
Capacity	Destruction rate, safety boxes capacity	District/subdistricts in Taylor (2003) that regularly used incinerators destroyed an average of 58 safety boxes per month, about 14 per week, equivalent to ~12 kg/week. Remote areas may only generate 1 kg per month. Proper sizing is important. Ideally, unit should burn for long periods (~4 hrs) to save fuel. (De Montfort units are not suitable for short sharp burns without a warm up period, though this appears to be common practice).
Temperatures	Primary chamber Secondary chamber Gas entering air pollution control devices, if any	540 to 980 C 980 to 1200 C (EPA 1990 recommendations) >850/1100* C (S. African and EU standards) >1000/1100* C (Indian and Thai standards) * more than 1% chlorinated organic matter in waste <230 C
Residence times	Gas (secondary chamber)	>1 s
Air flows	Total combustion air Supply and distribution of air in the incinerator Mixing of combustion gas and air in all zones Particulate matter entrainment into flue gas leaving the incinerator	140 – 200% excess Adequate Good mixing Minimize by keeping moderate air velocity to avoid fluidization of the waste, especially if high (>2%) ash waste is burned.
Controls & Monitoring	Temperature and many other parameters	Continuous for some, periodic for others
Waste	Waste destruction efficiency	>90% by weight
	Uniform waste feed Minimizing emissions of HCl, D/F, metals, other pollutants Load/charge only when incinerator operating conditions are appropriate	Uniform waste feed, and avoid overloading the incinerator Avoid plastics that contain chlorine (polyvinyl chloride products, e.g., blood bags, IV bags, IV tubes, etc. Avoid heavy metals, e.g., mercury from broken thermometers etc. Pre-heat incinerator and ensure temperatures above 800 C. Avoid overheating.
Enclosure	Roof	A roof may be fitted to protect the operator from rain, but only minimum walls.
Chimney	Height	At least 4 – 5 m high, needed for both adequate dispersion plus draft for proper air flow
Pollution control equipment	Installing air pollution control devices (APCD)	Most frequently used controls include packed bed, venturi or other wet scrubbers, fabric filter typically used with a dry injection system, and infrequently electrostatic precipitator (ESP). Modern emission limits cannot be met without APCD.

In practice – and in contrast to the guidelines above – incinerators usually are located within 10 to 30 m of clinics/hospitals for reasons of convenience, management, etc., and they often are located adjacent to or within populated areas. Several cases of incompatible siting are documented in Figure 5.

Figure 5 Photos indicating siting problems due to proximity to populated areas or poor dispersion potential.
Left: children's park next to the incinerator at Kulathummel Salvation Army Hospital, India (WHO, taken from HCWH 2002); Center: unknown, reported in Adama (2003); Right: Kenya, reported in Adama (2003).

3.4 Construction

Adequate plans, drawings, and quality control are necessary to construct incinerators. Dimensional drawings, tolerances, material lists, etc. are necessary.[9] The Kenya survey (Taylor 2003) indicates a lack of adequate quality control in the construction phase, resulting in incorrectly-built facilities. Further, shelters, protective enclosures, and pits have not been constructed at most sites.

3.5 Operation

3.5.1 General operating (prior and following loading)

Proper operation is critical to achieving design parameters. In general, the manufacturer or designer of the equipment should provide a manual that discusses operating practices including startup procedures, shutdown procedures, normal operation, troubleshooting, maintenance procedures, recommended spare parts, etc. These will be equipment-specific. Some general operation issues are listed in Table 3.

[9] Currently, the De Montfort plans available on the web are not dimensional but are drawn in terms of bricks. This may allow flexibility and lower costs given variations in brick sizes (DJ Pickens, personal communication, Dec. 15, 2003). Dimensional drawings would standardize construction, facilitate repairs with interchangeable components, and potentially increase performance. Dimensional plans are considered essential for proper construction.

Table 3 Operation and maintenance issues for small incinerators.

Factor	***Example***
Waste selection	Restricted wastes
Waste-feed handing	Volume, moisture
Incineration operation, monitoring and control	Recharge, fuels, temperature
Air pollution control systems, if any	Filters
Maintenance	Hourly, weekly, monthly, annual, control equipment
Control and monitoring instrumentation	Temperature, pressure, smoke/opacity
Recordkeeping	Operating records, maintenance records
Safety	Infection control during waste handling, equipment safety, fire safety

EPA (1990) has a thorough guide to operating procedures for hospital waste incinerators, including small batch and intermittent units. While not all sections of the guide are relevant to low cost small-scale incinerators that lack monitoring, automatic controls and other features, many aspects are very relevant, thus, portions of this guide have been reproduced in Appendix C. A guide specifically tailored to the De Montfort incinerator is under development (T. Hart, personal communication, Dec. 15, 2003). The De Montfort incinerator reports and web site also makes several recommendations:

- The incinerator must be fully heated up before wastes are added, requiring about 30 min or longer, depending on ambient temperature, type of fuel, fuel moisture content, etc. However, most of the 14 small-scale units surveyed in Kenya (Taylor 2003) were not being operated in this fashion, rather, safety boxes were loaded prior to lighting.
- Firewood must have a low moisture content (<15%)
- Temperature monitors are not used, thus there is no indication that suitable temperature have been reached.
    - Grey or black smoke indicates poor combustion and low temperatures.
    - Low cost dial type readout temperature sensors should be available for a reasonable cost and it is strongly suggested that units incorporate a quantitative temperature gauge, and that waste only be combusted when the temperature is in the correct range.
- Manual operation requires the constant presence of an operator when burning waste. Dry fuels must be added every 5 – 10 min.
- Flame must not be extinguished during burnings.
- Grates must be regularly checked and raked to keep clear.

3.5.2 Waste loading/charging

- Proper amount of fuel should be present (2/3 full) before adding wastes
- Operator care, judgment, and experience necessary to deal with different load types
    - One safety box every 10 minutes appears to be an optimal rate for charging the De Montfort incinerator.
    - Very wet loads should be separated with drier material, and in extreme case supplemented by an extra increment of diesel/kerosene.
    - High heat fuels (plastics, paper, card and dry textiles) helpful to maintain temperature
    - Waste mixing is desirable. Mixing may be possible by separating waste types at the source in bags, labeling each, and loading in appropriate combination or sequence.
    - Operators should not sort and mix waste prior to incineration due to hazards.

  - Supplemental fuel may be need for wastes with a high moisture content or low fuel value.
  - Restricted wastes should never be burned, including radioactive wastes, mercury thermometers, or hazardous chemicals.
  - Because of the lack of emission controls, wastes containing chlorine, sulfur, nitrogen and toxic metals should be avoided.
- Measures may be necessary to hold wastes in position long enough to burn and to prevent them from failing through grate without being destroyed. This is especially important for smaller wastes, e.g., pills, sharps, etc. Straw or wood may be used to hold safety boxes in position. Sharps should be mixed with other waste.
- When the loading door is closed or opened rapidly, burning gases may come through the under air ports (air holes).
- Possible operator exposure due to smoke, flames, heat when loading door is opened or rapidly shut
- The operator should open the door while standing at the front of the incinerator (to protect from blowback), wait a few seconds for any blowback to subside, and load from the side.

3.5.3 Burndown/cooldown

- Sufficient time must be provided for the 'fixed carbon' in the waste bed to combust. A recommended period is 1 hr plus an additional 20 min for each hour of operation or typically 2 to 5 hr total (EPA 1990), but this will depend on many factors.

3.5.4 Monitoring

Combustion and emission monitoring is used routinely for several purposes, including determining whether incinerators are properly operated. Additionally, monitoring is used to assure compliance with regulatory limits and, to an extent, to help build public trust. Monitoring may be classified into the following categories:

- Sensory observations, e.g., visual assessment of stack emissions or assessment of odors. This is similar to methods practiced 30 or (many) more years ago. Sensory monitoring is clearly unable to detect many emissions of concern, and is very subjective.
- Stack tests, e.g., measurement of emissions for brief periods of time. Stack testing started in the 1970s, and is still widely used for special tests (dioxins, metals, etc.) These tests are expensive, and provide emission data for only a brief period of time that may not be representative.
- Continuous emission monitoring (CEM), e.g., in-stack monitoring of opacity (particle surrogate), SO_2, CO, O_2, NO_x, HCl and recently Hg is regularly conducted at modern incinerators. CEM is required for larger incinerators. Continuous monitoring of temperature and other parameters (e.g., pressure drop across filters) is also used (and often required). CEM data have been used as surrogates of emissions and to indicate the suitability of combustion conditions, although there are issues, e.g., correlation of CO to products of incomplete combustion (PICs) is poor at low CO levels.
- Environmental monitoring. While used infrequently, monitoring of ambient air, soil, food, etc., around incinerators has been used to confirm predictions of multimedia exposure models .

Low-cost and locally-built incinerators have minimal if any capability to monitor operations, including emissions or combustion conditions, other than the use of sensory observations. It is suggested that operators might never know that they are properly operating the incinerator without a temperature gauge and more training (described below).

3.5.5 Safety

Safety considerations include prevention of infection, equipment safety (to prevent operator injury), and fire safety. Some specific recommendations include:

- Eye protection and a face mask should be worn when opening loading door or visually checking the unit to protect against glass shards from exploding ampoules and glass bottles.
- Heavy-duty gloves and apron should be worn when handling health-care waste.
- Ash must not be handled by hand.
- An adequate cool-down period (3 to 5 hrs) is necessary before ash removal.
- Appropriate disposal of ash is necessary.

3.6 Maintenance

Regardless of how well equipment is designed, wear and tear during normal use and poor operation and maintenance practices will lead to the deterioration of components, a resultant decrease in both combustion quality, an increase in emissions, and potential risks to the operator and public. Operation and maintenance also affect reliability, effectiveness and life of the equipment. Essentially all components of small-scale incinerators are prone to failure and require maintenance. Maintenance on an hourly to semi-annual schedule is required (EPA 1990). A typical maintenance/schedule for a small-scale incinerator is shown in Table 4.

Table 4. Typical maintenance schedule for incinerators (derived in part from EPA 1990).

Activity Frequency	***Component***	***Procedure***
Hourly	Ash removal	Inspect and clean as required
Daily	Temperature, pollution monitors, if any	Check operation
	Underfire air ports	Inspect and clean as required
	Door seals	Inspect for wear, closeness of fit, air leakage
	Ash pit	Clean after each shift
Weekly	Latches, hinges, wheels, etc.	Lubricate if applicable
Monthly	External surfaces of incinerator and chimney (stack)	Inspect external hot surfaces. White spots or discoloration may indicate loss of refractory
	Refractory	Inspect and repair minor wear with refractory cement
	Upper/secondary combustion chamber	Inspect and remove particulate matter accumulated on chamber floor
Semi-annually	Hot external surfaces	Inspect and paint with high temperature paint as required
	Ambient external surfaces	Inspect and paint as required

For small-scale low cost incinerators, components particularly prone to failure that are mentioned in several reports include (Taylor 2003; HCWH 2002):

- Firebox access doors and frames that warp, hinges that seize and break, and assemblies that break free of mortar.
- Grates that distort, break, or become clogged.
- Chimneys (stacks) that are badly corroded and chimney supports (guy wires) that are not adequately attached, broken, loose or missing.

- Masonry, bricks and particularly mortar joints that crack.
- Grills that are damaged or missing.
- Steel tops that warp and short-circuit the secondary combustion chamber.

De Montfort incinerators typically require major maintenance after 3 years, costing approximately 70% of initial construction costs (Taylor 2003). Funds must be made available to provide for both routine and major maintenance. The use of service contracts may be appropriate.

3.6.1 Facility inspection

As currently used, stack gases or necessarily even basic combustion process parameters like temperature are not monitored in small-scale incinerators. There is a need for even basic facility inspections to ensure that the unit is in proper repair and that compliance with best operating practices is feasible (Kentucky 1996). Facility inspections should include:

- Visual inspections of the facility for corrosion, leaks, mortar and seal failures, etc.
- Testing of doors and other moving parts.
- Regular schedule, e.g., monthly to quarterly.
- Documentation of use, maintenance, and complaints.
- Reporting of findings to higher authorities.

A trained operator can provide this inspection, however, an independent assessment would provide greater independence and impact. Ideally, a governmental Environmental Health Officer or Air Pollution Control Specialist, along with the certified operator, would conduct an inspection twice per year.

3.6.2 Record keeping

Records must be maintained for maintenance activities to prevent premature failure of equipment, increase life, track performance, evaluate trends, identify potential problems areas, and find appropriate solutions. In current practice, few if any records are maintained.

3.7 Training and management

3.7.1 General duties

Proper operation of incinerators is necessary to minimize emissions and other risks. Only a trained and qualified operator should operate or supervise the incineration process. The operator must be on-site while the incinerator is operating. Without proper training and management support, incinerators cannot achieve proper treatment and acceptable emissions, and the resultant risks due to incineration can greatly increase and may be unacceptable. Based on the Kenya survey (Taylor 2003), training and the commitment to training is inadequate and represents and important factor in the poor adoption of small-scale incinerators. The same report indicates that operator training is the first and foremost need. A certification process for operators and supervisors is suggested below.

3.7.2 Operating and maintenance manual

The manufacturer or designer of the incinerator should provide operation and maintenance manuals that provide specific instructions for their equipment translated to the local language. These manuals should be incorporated into a best practices guide for each type or version of incinerators.[10]

[10] IT Power India is developing a manual that covers operation of the De Montfort incinerator. (personal communication, T. Hart, Dec. 15, 2003).

3.7.3 Operator certification

Operator certification following a defined process is suggested to ensure proper operation and use to minimize emissions and other risks associated with incinerator. Additionally, proper operation and maintenance will improve equipment reliability and performance, prolong equipment life, and help to ensure proper ash burnout (EPA 1990).

Typically, certification involves both classroom and practical training.

Adequate classroom training is demonstrated by the completion of an approved training program. An approved program would include the following components:

- Coverage of the following:
    - Fundamental concepts of incineration
    - Risks associated with health-care waste and waste incineration
    - Waste reduction, segregation and handling goals and practices
    - Design, operation, maintenance of the specific incinerator used
    - Operation problems and solutions (e.g., white smoke, black smoke, etc.)
    - Operator safety and health issues
    - Community safety and health issues
    - Best practices guide for the specific equipment including appropriate fuels, frequency of burns, etc. This will need to be tailored to both the equipment plus waste stream at the site.
    - Inspection and permitting
    - Record keeping (operation and maintenance activities)
- At least 24 hours of classroom instruction.
- An exam created and given by the course instructor.
- Reference material covering the course given to the students

Practical training is necessary in addition to classroom training. Practical training can be obtained by demonstration that the operator has either:

- Operated an incinerator for six months.
- Supervised a qualified incinerator operator for six months.
- Completed at least two burn cycles under the supervision of a qualified personnel.

3.8 Regulations affecting incinerators

3.8.1 Emission limits

Emission limits are applicable to a best practices guide. Table 5 shows current regulatory limits in the US and the EU. Emission factor–based estimates for controlled air incinerators without air pollution control equipment (AP42, EPA 1995) are shown for comparison.

- The US EPA promulgated emission limits for incinerators under the 1997 "Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Hospital / Medical / Infectious Waste Incinerators" (EPA 1997). All existing incinerators were to be in full compliance by September 2002. The US EPA also subjects new incinerators to a 5% visible emission limit for fugitive emissions generated during ash handling, a 10% stack opacity limit, and other restrictions.
    - Standards vary by incinerator capacity and whether it is an existing or new facility.

- The standard setting process is based largely on the best performing units in the mid-1990s, thus the basis of the standards is technical feasibility and cost-effectiveness. However, to site and permit a facility, local authorities may require health risk assessment.

- EU limits were promulgated in 2000 (CEC 2000). Periodic tests are required to ensure standard attainment.
  - Standards are based in on the fifth Environment Action Programme: Towards Sustainability, a European Community programme of policy and action in relation to the environment and sustainable development, supplemented by Decision No 2179/98/EC that require that critical loads and other limits on nitrogen oxides, sulfur dioxide, heavy metals and dioxins should not be exceeded, with the goal of public health protection. Additionally, this program set goals of 90% reduction of dioxin emissions of identified sources by 2005 (1985 level), and 70% reduction for cadmium, mercury and lead emissions in 1995. For dioxins, the EU standard reflects the protocol on persistent organic pollutants signed by the EC within the framework of the UN Economic Commission for Europe (UN-ECE) Convention on long-range transboundary air pollution that contains legally binding limit values for dioxins and furan emissions (0.1 ng TEQ/m^3 for installations burning more than 3 tons/hr of municipal solid waste, 0.5 ng/m^3 for incinerators burning more than 1 ton/hr of medical waste, and 0.2 ng TEQ/m^3 for installations burning more than 1 ton/hr of hazardous waste.
  - The final directive (CEC, 2000) applies to all size ranges (size classes in earlier versions of the directive were removed).

- WHO has not developed a guideline value for emissions from a single source such as incinerators.

Existing regulatory limits show considerable divergence for particulate matter, dioxin/furans and several metals, in part a result of the different means used to set standards.

The AP42 emission factor estimate for PCBs in Table 5 is striking. (AP42 is not a standard, but a compilation of emission data.) Published data on PCB concentrations in incinerator discharges are sparse, and emissions can vary considerably between incinerators. In general, concentrations of dioxin-like PCBs to contribute a minority of the total dioxin toxic equivalents. Neither US nor EU standards control PCB-TEQs, though the FAO/GAO provisional intake guideline value does include co-planar PCBs.

Table 5 Regulatory limits for pollutant emissions from incinerators.

Pollutant	***Units***	***EPA LIMITS-New Units***			***EPA LIMITS - Existing Units***				***EU Limits***			***AP42***
		Small	***Medium***	***Large***	***Rural***	***Small***	***Medium***	***Large***	***Daily***	***Hourly***	***4 hr***	***Emissions***
Particulate Matter	mg/dscm	69	34	34	197	115	69	34	5	10		223.0
	gr/dscf				0.086	0.05	0.03	0.015				
Carbon Monoxide	ppm(v)	40	40	40	40	40	40	40	50	100		127.0
Dioxins/Furans	ng/dscm total	125	25	25	800	125	125	125				
	ng/dscm total TEQ	2.3	0.6	0.6	15	2.3	2.3	2.3			0.1	4.1
PCB TEQ	dscm total TEQ											2329.8
Organics	mg/dscm								5	10		15.0
									total Cl			
Hydrogen Chloride	ppm(v)	15	15	15	3100	100	100	100	5	10		1106.2
	or % reduction	99%	99%	99%		93%	93%	93%				
Sulfur Dioxide	ppm(v)	55	55	55	55	55	55	55	25	50		54.6
Nitrogen Oxides	ppm(v)	250	250	250	250	250	250	250	100	200		93.0
Lead	mg/dscm	1.2	0.07	0.07	10	1.2	1.2	1.2				3.6
	or % reduction	70%	98%	98%		70%	70%	70%				
Chromium	mg/dscm											
Cadmium	mg/dscm	0.16	0.04	0.04	4	0.16	0.16	0.16			0.05	0.3
	or % reduction	65%	90%	90%		65%	65%	65%				
Mercury	mg/dscm	0.55	0.55	0.55	7.5	0.55	0.55	0.55			0.05	5.4
	or % reduction	85%	85%	85%		85%	85%	85%				

Notes for table:

1. US EPA capacities: small = less than or equal to 91 kg/hr (200 lbs/hr); medium = 91 – 227 kg/hr (200 - 500 lbs/hr; large = greater than 227 kg/hr (500 lbs/hr). Also, regulations for monitoring, operator training, opacity and siting not shown.
2. mg = milligrams; dscm = dry standard cubic meter; ppmv = parts per million by volume; ng = nanograms TEQ = toxic equivalent, concentrations at 7% O2.
3. EU standards not shown for thallium, copper, manganese, nickel, arsenic, antimony, cobalt, vanadium, tin, O_2.
4. AP42 emissions (EPA 1996) for incinerators without air pollution control equipment shown for comparison.

Incinerators generally cannot meet modern emission standards without emission controls.[11] For example, Ferraz (2003) determined that dioxin concentrations in combustion gas were 93 to 710 times higher than the (EU) legal limit (0.1 ng TEQ/m^3), depending on the waste composition. One new control approach appears very promising, namely, catalytic filter technology that removes dioxins and furans, along with particulate matter. This essentially passive technology can be retrofitted in existing baghouses, typically following water quenching and dry scrubbing, and it appears cost-effective

[11] The Mediwaste incinerator, powered by propane, appears to meet EU standards without additional air pollution controls, a possible exception to this statement.

(Fritsky et al. 2001). However, it is not likely adaptable to small-scale units that do not have exhaust fans, any pollution controls, much less the needed infrastructure.

In summary, small-scale locally-built incinerators appear unlikely to meet emission limits for carbon monoxide, particulate matter, dioxin/furans, hydrogen chloride, and possibly several metals and other pollutants.

3.8.2 Permitting

A permitting program of facilities may be a useful means – and likely the only means – to ensure compliance with best practices guideline. Permitting programs are generally mandatory and would normally include the following:

- *Design review*: Permitting is a means of ensuring that only acceptable incinerator equipment is constructed and utilized, e.g., incinerators should utilize a secondary combustion chamber, a chimney of specified height, etc.
- *Safe operation*: Penalties or shut-down for repeated noncompliance of best practices guidelines should be considered.
- *Maintenance*: Regular inspections are required to ensure adequate maintenance.
- *Operator certification*: Training of the operator(s) and supervisory personnel must be documented.
- *Inventory and record keeping*: Authorities should inventory incinerator facilities and track utilization.

3.8.3 Global conventions

The final version of the Stockholm Convention on Persistent Organic Pollutants (POPs) was adopted in May 2001 and is now in the process of ratification. Annex C deals with the unintended production of POPs, which include dioxins and furans. The Convention specifically targets incinerators. Among other actions, it will require counties to develop and implement actions to address the release of dioxins and furans; Article 5 will require measures to reduce dioxin/furan releases from incinerators with the goal of their “ultimate elimination;” and countries are required to promote the use of alternatives including the use of the best available techniques/technologies.

Under the Stockholm Convention, incinerators are not a preferred technique due to their potential to emit POPs. Only highly controlled incinerators with air pollution control equipment and operational practice specifically designed to minimize dioxin formation and release could be considered the best available technology.

3.9 Emission standards for small-scale incinerators

It is not recommended that WHO develop or specify emission standards or guidelines for small-scale incinerators. Such standards require quantitative emission limits on each type of pollutant, and standards require the use of inspection, testing, monitoring and certification programs for incinerators and operators to ensure compliance. Small-scale low cost incinerators will not meet modern emission standards for many pollutants, e.g., carbon monoxide, particulate matter, dioxin/furans, hydrogen chloride, and possibly several toxic metals. To meet emission standards, incinerators must be designed to use air pollution control equipment (removing particles, acid gases, etc.), combustion process monitoring (temperature, flow rates, etc.), and process controls (waste, fuel, air flows). Few of these technologies are adaptable to small-scale low cost incinerators that do not have exhaust fans, pollution controls, dampers, monitoring, electrical power, etc. These technologies will greatly increase the cost and complexity of incinerators, and they are unlikely to perform reliability in many settings given the need for careful operation, regular maintenance, and skilled operators.

Where incineration is used, national governments might utilize emission limits and other requirements to ensure effective waste treatment, minimize emissions, and decrease exposure and risks to workers and the community. This should include the use of approved incinerator designs that can achieve appropriate combustion conditions (e.g., minimum temperature of 800 C, minimum chimney heights); appropriate siting practices (e.g., away from populated areas or where food is grown); adequate operator training (including both classroom and practical training); appropriate waste segregation, storage, and ash disposal facilities; adequate equipment maintenance; managerial support and supervision; and sufficient budgeting.

4 Exposure and health risks from incineration

Section 6.1 presents the conceptual framework of health risk assessment (HRA), as well as some details and citations supporting the approach. Subsequent sections apply this approach to small-scale incinerators.

4.1 Health risk assessment framework

The objective of HRA is to estimate effects of incinerator emissions, in this case, air pollutants, on human health, including short-term acute impacts (systemic diseases) and chronic (long-term) impacts (e.g., cancer). The goal generally is to assess the overall risk associated with exposure to emissions, e.g., the 'risk' quantified as the probability of harm, the fraction of the population potentially affected, and/or the number of cases of disease.

Historically, health concerns raised by incineration focused on communities living near the incinerator. More recently and rather definitively, the NRC (1999) identified three potentially exposed populations: (1) the local population, which is exposed primarily through inhalation of airborne emissions; (2) workers at the facility, especially those who clean and maintain the pollution control devices; and (3) the larger regional population, who may be remote from any particular incinerator, but who consume food potentially contaminated by one or more incinerators and other combustion sources that release persistent and bioaccumulative pollutants

The analysis will follow the general steps of hazard assessment, toxicity assessment, exposure assessment, and risk characterization, as summarized below. The assessment is screening in nature, as described below.

4.1.1 Hazard assessment

In hazard assessment, causative agents are identified and the feasibility of linkages and mechanisms between air pollutants and adverse health effects are demonstrated. Much of this has been completed by the development of lists of priority chemicals, regulations, etc.

4.1.2 Dose-response assessment

The dose-response assessment describes the toxicity of the chemicals identified above using models based on human (including clinical and epidemiologic approaches), and animal studies. Dose-response relationships depend on the pollutants:

- Systemic toxicants. Many studies have indicated a threshold or 'no-effect' level, that is, an exposure level where no adverse effects are observed in test populations, as cell mechanisms are able to repair or isolate damaged cells. Some health impacts may be reversible once the chemical insult is removed. In this case, a reference dose or concentration, for use in the risk characterization as a component of the hazard index.
- Carcinogens. Both linear and nonlinear dose-response models are used for carcinogens. With linear models, doubling the exposure doubles the predicted risk. Cancer potencies are typically provided for each exposure pathway or for total intake.

- "Conventional" pollutants, e.g., particulate matter and SO_2. Dose-response relationships for morbidity and mortality are often derived using epidemiological studies.

High quality peer-reviewed databases should utilized, e.g., US EPA's Integrated Risk Information System (IRIS), WHO, IARC, etc. It is important to realize that these databases are primarily useful for long-term exposures to toxics.

The dose-response analysis involves a review of the literature to summarize the basis of the dose-response relationship, the nature of studies, health endpoints, the weight of the evidence, uncertainties, extrapolations, and other adjustments used to derive the dose-response relationship. Analyses should emphasize those agents that are judged to cause most of the risks and human health impacts.

4.1.3 Exposure assessment

The exposure assessment identifies exposed populations and details the type, level, duration and frequency of exposure. Typically, exposure assessment consists of a number of steps.

- Estimation of ambient air concentrations using air pollution monitors or other predictive air quality models, including analysis of spatial and temporal trends and distributions
- Identification of any special groups that may be at risk due to high exposure (due to proximity, diet, or other factors) or vulnerability (due to preexisting disease or other factors) to the pollutants. Special groups often include children and pregnant women.
- Development of appropriate exposure assumptions, e.g., activity factors (e.g., time spent outdoors), locational factors (mobility), uptake/dosimetry factors (breathing rates, absorption rates, etc.), and other factors that may affect exposure to pollutants for each group.
- Estimation of the numbers of exposed individuals based on demographic and other data.
- Validation of exposure analysis using monitoring or other means.

Several exposure 'pathways' may pose risks. Figure 6 provides the conceptual framework for the HRA recently used for air toxics in the US. Only the portion in bold in the figure was attempted in this large study. This diagram is useful for orientation purposes as it describes linkages from emission sources to measures of health risk impacts.

The 'indirect exposure pathways' for air pollutants may pose significant health risks in certain settings. These pathways may include, for example, consumption of locally produced meat, eggs, and dairy products, consumption of fish from local waterways that are contaminated by air pollutants, and dermal contact with contaminated soils. These pathways are important for persistent pollutants that can bioaccumulate into food, a result of the deposition of toxic emissions onto plants and soil with subsequent ingestion by farm animals, or, in the case of fish contamination, from deposition directly into water bodies or onto soil and runoff into surface waters with subsequent uptake in fish. Indirect exposure pathways can be important for dioxins, furans and other emissions if:

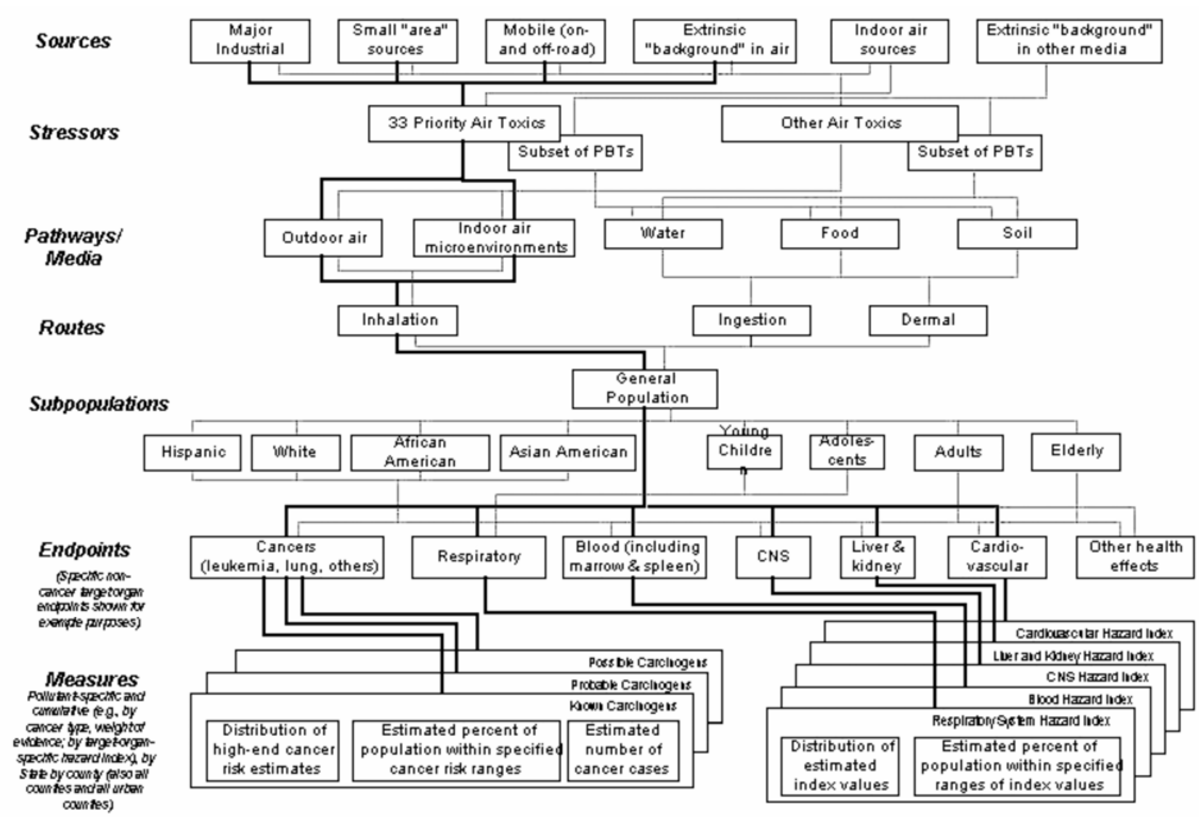
- Food is grown near the incinerator.
- Animals are raised on fields near the incinerator.
- Lakes, ponds, or other surface drinking water sources have a local catchment area.
- Subsistence fishers or farmers in the area obtain most of their food from local sources.
- Children play in dirt subjected to significant atmospheric deposition.

Modeling of indirect exposure pathways involves considerable uncertainty and difficulties for several reasons: (1) The methodology is relatively new, complex, under refinement and peer review; (2) substantial site-specific parameters – that may not be available – are required; and (3) validation efforts using measurements of contaminants along the pathway (e.g., in food, blood, urine, etc.) are tremendously important to ensure model credibility and the significance of air emission sources. Indeed, recent follow-up studies in developed countries have collected and analyzed a sufficient number of samples to characterize trace metals, dioxin/furans, and other pollutants emitted from major point sources, in soils and foods. Challenges involved in predicting and validating indirect exposure pathways for small-scale incinerators include:

- The limited data available on both communities surrounding incinerators (demography, occupations, health status, etc.) as well as environmental conditions (types and concentrations of air contaminants present, etc.)
- The wide variety of environmental settings.
- The poor quality of the emission data.
- The lack of validation of the exposure assessments.

As can be seen, exposure assessments can be very detailed and data intensive. Given uncertainties, simpler analyses also have a role, and they may be more robust, more transparent, and often more useful.

Figure 6 Specific conceptual model for the US National Scale Air Toxics Assessment.
From EPA 2003, Framework for Cumulative Risk Assessment.



4.1.4 Risk characterization

Risk characterization determines the overall risks of exposure. Generally, multiplicative relationships between the dose-response relationship, pollutant exposure, and population exposed are used for each chemical and affected population to identify major pollutants causing risks, the magnitude of the risk, the populations with the maximum risk, and the number of people likely to be affected. To gauge the significance of these risks, results often are compared to other environmental and societal risks. Risk characterizations provide information that can help to rank and prioritize risks, anticipate future monitoring needs, and evaluate alternative management strategies.

Risk characterization should include an uncertainty analysis that includes: a discussion of alternative exposure characterizations; alternative dose-response characterizations; weight-of-evidence discussions; and evaluation of uncertainties in the exposure assessment.

4.1.5 Uncertainties, variability and data gaps

Despite considerable effort and progress in evaluating health risks of incineration in developing countries, there are several critical data limitations and inadequacies, including (NRC 1999, McKone 2000, Snary 2002):

- *Limited availability of emissions data for characterizing events other than normal operation*. Dioxins and many other organic compounds are products of incomplete combustion (PICs). PICs are minimized under ideal combustion conditions, including appropriate temperature, residence time, and turbulence conditions. Emissions are likely to be much greater under when the incinerator is started, shutdown, charged with waste and fuel, or if an upset occurs. Relatively few stack samples for each pollutant are collected and analyzed. There is virtually no information regarding emissions under upsets or even less than optimal conditions.
- *Exclusion of workers and larger regional populations*. Workers come into close contact with stack emissions, and they also clean and maintain equipment, remove and dispose of ash, etc. Incinerator operators may have elevated exposures to dioxins, lead and other metals, particulate matter, PAHs, urinary mutagens and other pollutants. While emission restrictions are intended to reduce emissions from the facility, they may not change work conditions and worker exposure.
- *Insufficient data for characterizing intermedia transfers of emitted chemicals from ambient air to food webs and indoor environments.* These indirect multimedia, multipathway exposures remain poorly characterized, and there is a continuing absence of scientific studies, models, and direct measurements of human contact. Both measured data and models, including the intermedia transfer factors (ITFs) used to predict indirect exposures, have low reliability.
- *Inadequate justification for assumptions (e.g., pathways selected) and inadequate peer review*. Many simplifying assumptions are required.

All of these concerns apply to small-scale incinerators. Furthermore:

- Actual emissions from small-scale incinerators in-use under field conditions are unknown.
- The ability to achieve and sustain low emissions from small-scale incinerators by best practices at present is unknown but seems unlikely.
- Field data exists for validation and for reducing uncertainties, e.g., dioxin measurements in milk, are largely absent.

4.1.6 Comparative and screening risk assessments

Risk assessment can provide a useful contribution to decision-making, policy development, and standard setting. Such assessments can be used to help evaluate preferred options for health-care waste treatment. In this context, it is important to distinguish two applications for risk assessment:

- *Comparative assessments* in which one or another option is preferred due to presumed lower risks.

- *Screening assessments* in which case estimates of probable to maximum (worst-case) risks are compared to some norm or standard, e.g., acceptable risk level,[12] maximum number of individuals affected, 99.99% disinfection rate, etc. As a result:
    - o Preferred options would fall well below the norm or standard. The logic is that under typical rather than worst-case conditions, risks of preferred options should be even lower. Further analysis may not be warranted.
    - o Options exceeding the norm or standard should either be eliminated from consideration, or they require further and more refined analysis, e.g., using site-specific conditions, monitoring, etc.

Both comparative and screening assessments should make assumptions well-founded and explicit, use the best available information in models, and discuss, bound and otherwise treat uncertainties. Also, both types of applications should consider relevant technical, social and economic factors, e.g., the presence of acceptable options that might restrict technical options, e.g., immediate elimination of incinerators.

In theory, comparative risk assessments of incineration and other waste treatment options can be credible and useful. Practically, however, this appears difficult or infeasible given the very large uncertainties in attributing health impacts to incinerators. When uncertainty and variability become large, it is difficult to interpret or assign relevance to the estimated magnitude of exposure and health risk (NRC 1999). As a simple example, assume technology A yields a maximum predicted individual lifetime risk of 10^{-2} and an average population risk of 10^{-6}, while technology B gives individual and population risks of 10^{-4} and 10^{-5}. Technology A might be preferred as the maximum individual risk is reduced 100-fold, yet technology B might be preferred as the broader risks are reduced 10-fold. Uncertainties in each case might be 100-fold and thus the risk information might have very little relevance to the decision. While contrived, this example is relevant since available risk assessments due to small-scale incinerator emissions are incomplete and uncertain for reasons discussed earlier.

A second issue with comparative assessment deals with comparisons and valuations of different types of impacts. For example, in comparing incinerator and non-burn technologies, different health endpoints must be assessed, e.g., chemical risks (cancer) versus infectious risks (hepatitis). Such situations may require the use of quality-adjusted life years (DALYs) or other such metrics, involving further assumptions and complexity.

Risk assessments used for screening purposes can avoid some of these issues. In this case, major difficulties can surround the selection of a norm (acceptable risk) and reasonable worst-case scenarios. Such assessments also involve variability and uncertainties, similar to comparative applications. However, screening applications do not use the numerical evaluation of risks as the sole or even primary evaluative criterion for decision-making.

The remainder of this section now turns to the specific analysis risks posed by dioxins and furans from small-scale incinerators.

4.2 Hazard identification – dioxins and furans

Incinerators produce dioxins (polychlorinated dibenzo-para-dioxins or PCDDs) and furans (polychlorinated dibenzofurans or PCDFs) (drawn in Figure 7) as a result of the combustion of chlorine-containing wastes, e.g., polyvinyl chloride and other plastics (WHO 2001; WHO 1999). Dioxin and furans include a group of chemically similar compounds (75 chlorinated dibenzo-dioxins

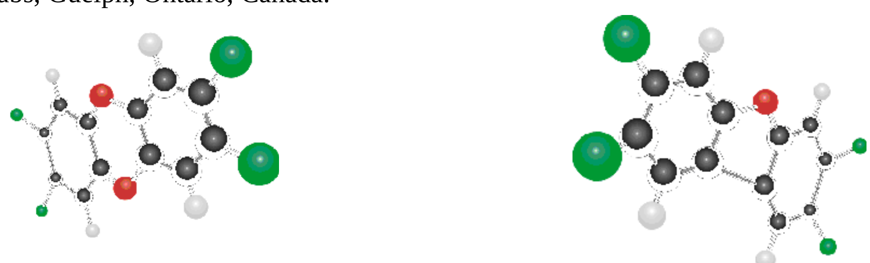
---

[12] The notion of acceptable risk level is subjective, context-specific, and based on available, but imperfect information. Some may believe that there is no "safe level" of exposure, e.g., the US EPA cancer risk model does not utilize a threshold effect. Others may believe that the assumptions and uncertainties inherent in risk assessments represent fatal flaws and such assessments should not be used to justify activities that may cause harm (instead of taking a precautionary approach). Pragmatically, risks that are small in comparison to other known risks may be acceptable, but many factors affect individual's views on this matter.

or PCDDs, and 135 chlorinated dibenzo-furans or PCDFs). These chemicals are toxic, persistent (do not readily break down in the environment) and bio-accumulative (able to move up the food chain). In general, exposure to dioxins and furans is mostly due to food intake (WHO 2001, Domingo 2002, Travis et al. 1999).

Human health risks due to dioxin and furan exposure have been reported extensively. Evidence for dioxin and furan toxicity in humans comes from studies of populations that have been exposed to high concentrations occupationally or in industrial accidents. Evidence for chronic low-level exposures in humans is more limited. The International Agency for Research on Cancer classifies 2,3,7,8 tetrachlorinated dioxin as a known human carcinogen based on to strong evidence on animal experiments and enough evidence on human studies (IARC 1997, WHO 1999). Short-term (called acute) exposures may result in skin lesions and altered liver function. Long-term or chronic exposure is linked to impairment of the immune system, the developing nervous system, the endocrine system and reproductive functions. The toxicity of the 17 dioxin/furans congeners that are tetrachlorinated in the 2,3,7 and 8 positions is generally determined by summing weighted concentrations to arrive at a toxic equivalent index, expressed as 2,3,7,8-TCDD equivalents (TEQs).

Figure 7 Molecules of 2,3,7,8-tetrachlorodibenzo-p-dioxin and tetrachlorodibenzofuran.
From Wellington Labs, Guelph, Ontario, Canada.



4.2.1 Dose response and exposure evaluation

There are several ways to consider dose-response relationships for dioxin/furans. Several are based on endpoints, others are based on relative doses or emissions. Several endpoints have been defined:

- *General toxicological effects.* WHO has established a tolerable daily intake (TDI) of dioxin/furans of 1 – 4 pg TEQ/kg-day, a provisional tolerable monthly intake (PTMI) for dioxins, furans, and dioxin-like polychlorinated biphenyls of 70 pg/kg of body weight (FAO/WHO, 2001). The PTMI is an estimate of the amount of the chemical dosage from all sources that can be ingested from food or water over a lifetime without appreciable health risk (WHO, 1996). For an adult with a body weight of 70 kg, this is equivalent to 4.9 ng TEQ/month or 59 ng TEQ/year. For a child weighing 15 kg, this is equivalent to 10 ng TEQ/year.
- *Carcinogenic effects*. US EPA expresses the probability of contracting cancer over a 70 year lifetime using an upper-bound cancer potency factor of 0.001 per pg TEQ/kg/day (EPA 2002). Typical risk benchmark values are 10^{-6} and 10^{-4}. For an excess lifetime cancer risk of 10^{-6}, the cancer potency factor yields an exposure of 0.001 pg/kg/day or 0.03 ng TEQ/year. For an excess cancer risk of 10^{-4}, the corresponding exposure is 0.1 pg/kg/day or 2.6 ng TEQ/year. (These values are 248 and 2.5 times lower than the WHO guideline.) EPA considers 2,3,7,8-dioxin to be a probable carcinogen.
- *Noncancer effects.* US EPA derived a range of 10 – 50 ng TEQ/kg body burden as a point of departure for calculating the margin of exposure (MOE), that is, the likelihood that noncancer effects may occur in the human population at environmental exposure levels. A MOE is calculated by dividing the human, or human-equivalent animal, lowest observed adverse effect

levels (LOAEL) or no observed adverse effect level (NOAEL) with the human exposure level of interest. MOEs in range of 100 to 1000 are generally considered adequate to rule out the likelihood of significant effects in humans based on sensitive animal responses.[13]

Background exposures. Exposures from incinerator emissions represent only a portion of an individual's total exposure. Exposures due to other sources, known as 'background exposures,' are especially important for dioxin/furans. For example, estimates for several developed countries show that most exposure comes via the dietary pathway, and only about 1% of total exposure arises from local incinerators (WHO 2001, Domingo 2002, Travis et al. 1999). Unfortunately, background exposures in developing countries are unknown, but they are also likely to be significant. Thus, it should be recognized that in many cases current exposures to dioxin/furans already approach or exceed recommendations, and that exposures from incinerators represent incremental exposures adding to the baseline exposure. This leads to the use of relative intake and relative emissions as indicators for evaluating the impacts of MWI exposures:

- *Relative intake rates.* Exposure due to MWIs can be compared to the background (current) exposure. Several estimates of background exposure are provided below.
    - Spain: Around an incinerator, the estimated dietary exposure was estimated as 43 to 77 ng TEQ/year (117 to 210 pg TEQ/day) (Domingo et al. 2002).
    - US: The adult daily exposure to dioxin-like compounds (as of the mid-1990s) averages 65 pg TEQ/day or 24 ng TEQ/year (EPA 2000); the median report in FAO/WHO (2001) is 42 pg TEQ /kg-month or 35 ng TEQ/year (70 kg person assumed). The median exposure to co-planar PCBs is 9 pg TEQ/month or 8 ng TEQ/year (70 kg person assumed) (FAO/WHO 2001).
    - Western Europe: The median exposure to dioxin/furan compounds is 33 to 40 pg TEQ/kg-month or 28 to 34 ng TEQ/person (70 kg person assumed). The median exposure to co-planar PCBs is 30 to 47 pg TEQ/month or 25 to 39 ng TEQ/year (70 kg person assumed) (FAO/WHO 2001).
    - Germany: Dioxin uptakes (via food) for the 1994-8 period are similar to that in the US. Based on a review by Parzefall (2002), adult intake ranges from 1.6 – 2.6 ng TEQ/kg-day, equivalent to 9 to 14 ng TEQ/year. Adult uptake ranges from 0.5 – 1.5 ng TEQ/kg-day, equivalent to 13 to 38 ng TEQ/year.
- *Relative body burden.* Increases can be compared to current tissue levels. US EPA estimates that tissue levels of CDD/CDF/PCB for the general adult U.S. is 25 ppt (TEQDFP-WHO98, lipid basis). This category can be viewed as similar to provisional tolerable intake values since the former is derived from 70 pg/kg-month dose intake of PCDDs, PCDFs, and coplanar compounds.
- *Relative emissions.* Both local and aggregate incinerator emissions can be examined in light of regional and/or global emissions. Continuous efforts to reduce environmental levels of dioxins/furans are required by addressing all sources, especially those indicated in recent inventories.
    - Current US emissions, for example, are estimated to be 3 300 TEQ g/yr.
    - Incinerators are believed to emit a significant fraction of the global emissions of dioxin and furans. In 1987, for example, medical waste incinerators were estimated to account for nearly 21% of known sources of dioxins and furans emissions in the US

[13] The US EPA Science Advisory Board review of the EPA dioxin reassessment indicates that the point of departure for the MOE is based on essentially a 99% confidence level and suggests that EPA harmonize the approach to that used for other chemicals that uses a 90% level. This would have the effect of increasing the point of departure.

(UNEP 1999). At the present, the fraction due to incinerators is likely to be considerably lower.

As a result of stricter emission standards for dioxins and furans promulgated in the last 10 years, dioxin and furan emissions have been significantly reduced in several countries (WHO, 1999). In Western European countries, dioxin and furan concentrations in many types of food (including mother's milk) have decreased sharply (UNEP, 1999). In the US, dioxin and furan intake from foods has also significantly decreased in recent years (EPA 2001). Thus, the use of the indicators suggested above, namely, relative intake rates and relative emissions, should utilize the most recent data.

4.3 Emissions of dioxins/furans from small-scale incinerators

This section estimates emissions from small-scale incinerators.

4.3.1 Emissions and dioxin formation

Incinerators release dioxin/furans to air via chimney (stack) exhaust and via fugitive releases, e.g., air leaks when charging the incinerator with fuel and/or waste. Dioxin and furans also may be contained in fly ash, in bottom ash and other dusts (though to a smaller extent), and in other waste streams, e.g., water and sludge discharges if a wet scrubber is used to treat exhaust gases. Dioxin/furan releases to air are believed to be the most significant exposure pathway (UNDP 2003). Air releases of dioxins/furans occur in both vapor and particulate phases (including sorbed to fly ash).

In combustion, dioxins/furans are formed by either (1) so-called "de novo" synthesis from dissimilar non-extractable carbon structures, and (2) by precursor formation/reactions via aryl structures derived from incomplete aromatic oxidation or cyclization of hydrocarbon fragments. Generally, formation may take place given the presence of a carbon surface or structure (e.g. fly ash), organic or inorganic chlorine, copper or iron metal ions (serving as catalysts), an oxidizing atmosphere, and, ideally, a temperature range of 250 - 450 C (Huang 1996). Dioxin/furan emissions depend on many factors, including:

- Chemical and physical characteristics of the waste (e.g., organic carbon, chlorine, ammonia, amines, metals, moisture, sulfur, ash contents).
- Process/combustion conditions (e.g., the availability of oxygen, chlorine, other precursors/catalysts, temperature, time, mixing/turbulence, reactor materials).
- Downstream conditions (e.g., temperature, residence time, precursor concentrations, the quantity and specific surface area of flyash).
- Presence and efficiency of air pollution control devices (e.g., wet scrubbing, dry absorption using lime, carbon, etc.)

While the understanding of dioxin/furan formation conditions is incomplete, some statements are generally supported, e.g., formation is roughly proportional to the post-combustion residence time in 200 – 400 C environment (e.g., Stanmore 2000). Even in high temperature incinerators (>800 C), temperatures may not be uniform and dioxins and furans can form in cooler pockets or during start-up or shut-down periods. Dioxin/furan formation is minimized by ensuring that incineration only takes place at temperatures above 800 C (Rossi and Schettler 2000).

4.3.2 Methods to estimate emissions

Dioxin/furan and other emissions can be estimated using several methods:

1. *Predictive models* based on statistical or physical-chemical processes (e.g., Stanmore 2000). The complexity and variability of the processes involved generally require measurements to characterize the performance of any specific incinerator, thus, available data do not allow use of predictive models for small-scale incinerators at this time.
2. *Stack gas measurements at specific incinerators*. This is the preferred approach, but relative few facilities are tested due to cost and other practical considerations.

3. *Stack exhaust measurements at comparable incinerators.*
4. *Emission factors* that relate the amount of pollutant emitted in the flue gas to the amount of waste incinerated. Several emission factors for dioxin/furan emissions from incinerators are available, however, their accuracy for small-scale incinerators may be questioned, mainly due to insufficient information about the wastes incinerated waste, e.g., Ferraz et al. (2003) recently has published factors for one incinerator design and 5 waste types. Ideally, separate emission factors would be required for each type of incinerator design, waste type, and possibly other factors.
5. *Regulatory standards/limits.* In risk assessments and other applications, an incinerator may be assumed to be emitting at the regulatory limit. This represents a maximum legal level or sometimes a worst-case scenario. Of course, this is not a worst-case scenario if true emissions exceed the regulatory limit. In cases, the regulatory standards/limits may be useful as they may reflect the emission rates that can be achieved using specific, typical, or best-available controls and practices, depending on the type of regulation.

The accuracy of any these methods will depend on many factors including the representativeness of the units sampled, combustion conditions tested, the variability in waste composition, the number of measurements available, and the performance of the emission testing method. Accuracies will vary by pollutant, e.g., emission estimates for dioxins/furans will be much less reliable than say NO_x or CO, in part reflecting capabilities of the measurement technologies. Indeed, EPA (1993) provides quality ratings for emission factors, giving “excellent” to NOx and CO, “above average” (uncontrolled) to “poor” for SO_2, and generally “poor” for other pollutants. For dioxins, the UNDP Dioxin toolkit (2003) states estimates are good to an order of magnitude (factor of 10) at best.

It is emphasized that estimates obtained from models, emission factors, and measurements at other sites will provide only preliminary estimates of air emissions, that the differences between measured and estimated emissions can be orders of magnitude, and that it may be difficult to bound uncertainties. Generally, the use of repeated tests on facilities of interest is the best way to determine air emissions from a particular source (EPA 1993).

4.3.3 Available estimates of dioxin/furan emissions

Table 6 lists measurements or estimates of dioxin/furans concentrations made in small-scale incinerator stacks. Concentrations derived from emission factors (discussed later) are also shown in the table.

Emission estimates range from non-detect to 4000 ng TEQ/Nm^3, though the upper end is based on measurements without a secondary combustion chamber (afterburner) tested in Thailand. SICIM and VULCAN incinerators are metal stove-like units that were tested in Cambodia. The highly loaded SICIM Case 2 test produced very high concentrations, possibly due to improper ratio of mixed hospital wastes (including safety boxes as well as plastic packaging, latex gloves, compresses and cotton pads) to complementary fuels (dry leaves and paper) (Oka 2003). Excluding the Thailand test, the highly loaded SICIM unit (Case 2), and the January 2001 test on the De Montfort unit that did not appear to utilize sufficiently sensitive measurement methods, emissions range from 0.14 to 300 ng TEQ/Nm^3. Excluding the UNDP estimate, the origin of which is unclear, the AP-42 estimate of 4 to 5 ng TEQ/Nm^3 is a central number. In developing these estimates, US EPA used test results at 37 incinerators that were felt to be representative and sufficiently complete. AP-42 excluded poorly maintained or operated incinerators (e.g., poor temperature control, need for repairs). It also excluded facilities with missing data, e.g., if process or waste is not adequately described. Typically, each qualified facility was tested 3 to 10 times.

Table 6 Measurements of dioxin/furan concentrations in chimney exhausts at small-scale medical waste incinerators.

Basis	*Type*	*Model*	*Date*	*D/F TEQ (ng/m3)*	*PCB TEQ (ng/m3)*	*Notes*
Emission tests on small scale units						
	SICIM	Case 1	Jun 01	26	3.6	Safety boxes, dry leaves
	SICIM	Case 2	Jun 01	600	29	Safety boxes, dry leaves, medical soft waste
	VULCAN	Case 1	Jun 01	7.4	0.22	Safety boxes, dry leaves
	VULCAN	Case 2	Jun 01	2.2	0.07	Safety boxes, dry leaves, medical soft waste
	DeMontfort	Mark 2/DMFU	Jan 01	Virtually none	-	Mixed medical waste, few needles
	DeMontfort	Mark 3	Jan 01	0	0	Wet texiles, general clinical and household waste, some diesel
	DeMontfort	Mark 1.1/T.1	May 03	0.03 - 0.14 (1)	0 - 19.9 (1)	Syringes and sharps boxes, > half full, 3300 needles/2 hrs
	Thailand	-	-	11 - 45 (7)	-	2 batch units with afterburners, alkali water APC, poorly maintained
Other emission tests and emission factors (2)						
	Portugal	Uncontrolled	2002	9 - 71	-	Rates depend on waste composition (Ferraz et al. 2002)
	AP-42	Uncontrolled	1993	4.1	2329.8	Average TEQ derived for available 13 reported D/Fs
	AP-42	Uncontrolled	1994	5.1	-	Average TEQ Update
	AP-42	Uncontrolled	1994	3 - 411	-	Range as reported in (Ferraz et al. 2002)
	UNDP	Class 1	2003	4000	-	simple batch box unit (no afterburner)
	UNDP	Class 2	2003	300	-	simple, small, controlled batch combustion with afterburner

Notes: (1) lower limit assumes non-detects at 0 concentration; upper limit assume non-detects at detection limit.

(2) Conversion to ng/m3 based on 10 m3 air/1 kg waste

(7) Reported in UNDP (2003)

After examining the available tests on small-scale incinerators, the accuracy of dioxin/furan measurements is judged to be poor for the following reasons:

1. Generally only a single measurement was obtained for a specific unit and type of waste.
2. The operating cycle when measurements were collected may not be representative of typical conditions.
3. Quality assurance aspects of measurements are not described, in cases non-standard methods are used, and method sensitivity (detection limits) were inadequate. In particular, tests of the small-scale units did not fully follow US EPA Method 0023A or European standard method EN 1948 (1996) for dioxins, or Method 1668A for PCBs. To obtain reliable results, very careful methods are needed, e.g. use of cooled probes, isokinetic sampling to capture particles as well as gases, careful clean-up, high resolution gas chromatography, low detection limits, etc.
4. Fuel characteristics, temperatures, and other parameters are not fully described.
5. Some estimates are derived using estimates of important parameters, e.g., UNDP (2003) derives rates assuming 20 m^3 air/kg waste for uncontrolled batch units and 15 m^3/kg for units with an afterburner in tests in Thailand, EX Corporation assumed 8 m^3/kg in tests in Cambodia, and US EPA assumes 10 m^3/kg.

Points 1 and 2 are especially important since considerable variability over the operating cycle is expected for batch- and intermittently-loaded incinerators. In particular, such incinerators have long warming and cooling phases that result in pyrolytic conditions in the furnace over extended periods, and the waste includes plastics containing high heating value and chlorine. These conditions are suitable for dioxin/furan formation, thus high emissions are expected (UNDP 2003). Furthermore, these units lack air pollution control equipment that can reduce emissions. Point 3 is also important as the upper (more conservative) estimate of De Montfort unit emissions is nearly completely driven by the method detection limits, rather than positive detection of actual compounds.[14]

4.3.4 Emission factor estimates

Table 7 lists available emission factors relevant to small-scale medical waste incinerators.

- AP42 estimates are from US EPA and were compiled in 1993. These are relevant to incinerators without air pollution control technology. The 12 units tested included batch, intermittent and continuously fed units. The reported emission factor is derived in TEQs using the average emissions reported for 13 (of 17 – not all) dioxin and furan congeners, and thus is somewhat underestimated. These incinerators had afterburners and were considerably larger (up to about 150 kg/waste per hour) than those considered in UNDP Classes 1 and 2. US EPA considers the data quality poor (grade "E") for the dioxin/furan estimates.
- UNDP Class 1 incinerators are very small and simple, small box type incinerators operated intermittently (in which a load of waste is ignited and left) with no secondary combustion chamber, no temperature controls and no pollution control equipment. As mentioned, UNDP (2003) considers the accuracy of dioxin/furan estimates to be within an order of magnitude.
- UNDP Class 2 "applies to all medical waste incinerators with controlled combustion and equipped with an afterburner, which, however, are still operated in a batch type mode. UNDP (2003) considers the accuracy of dioxin/furan estimates to be within an order of magnitude.

Ferrez (2002) and other have pointed out that emission factors strongly depend on composition of the waste incinerated. This is directly affected by the waste type, classification, segregation practice, and management methodology. Ferrez (2002) suggests that that emission factors not associated to the waste composition may have limited usefulness.

Table 7 Dioxin/furan emission factors relevant to small-scale medical waste incinerators.

Basis	*Type*	*D/F TEQ Emis (mg/Mg)*	*Notes*
AP-42	Uncontrolled	0.04	Based on 12 units, 13 congeners, 1993 document
AP-42	0.25	3.96	1996 update, short residence time
AP-42	0.5 s	0.91	1996 update, short residence time
AP-42	2 s	0.07	1996 update
UNDP	Class 1 (5)	40.00	simple batch box unit (no afterburner)
UNDP	Class 2 (5)	3.00	simple, small, controlled batch combustion with afterburner

4.3.5 Uncertainty and variability in emission factors

The estimates in Table 7 do not reflect variability and uncertainty. This is a key problem, especially since so few measurements are available for small-scale incinerators. To understand and estimates the variability, the data underlying the AP-42 estimates were examined and distributions derived for two key emission measurements, 2,3,7,8-TCDD and 2,3,7,8-TCDF. Figures 8 and 9 show the distribution of the measurements used in the AP42 emission factor. A lognormal distribution was fitted to these data using maximum likelihood estimates.

[14] The contract document for the 2003 tests of the De Montfort incinerator indicated that "Sampling will be for a continuous period of up to 6 hours and will be undertaken using a method as far as possible in accordance with the requirements of BS EN 1948." However, test results show high detection limits that render these tests inaccurate.

Figure 8 Distribution of emission factor estimates of 2,3,7,8 TCDD at uncontrolled incinerators. Based on 50 measurements from 12 facilities using AP42 data (EPA 1995). Fitted distribution shown as solid line.

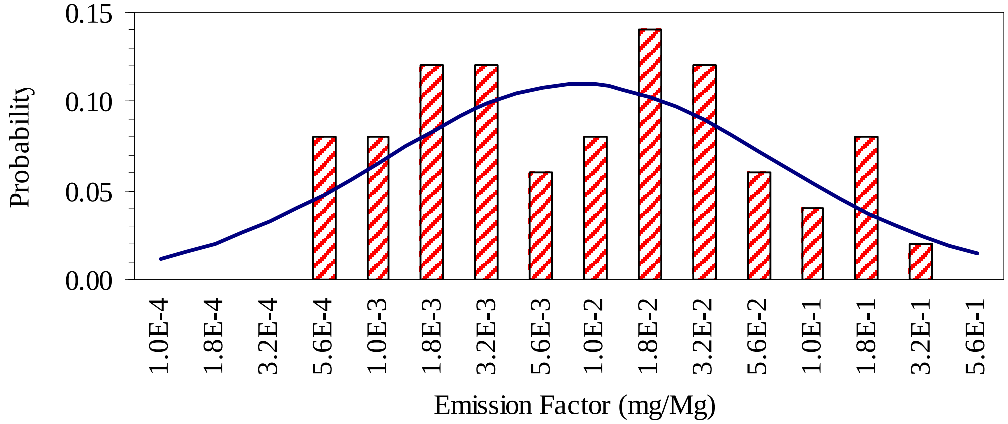


Figure 9 Distribution of emission factor estimates of 2,3,7,8 TCDF at uncontrolled incinerators. Based on 60 measurements from 12 facilities using AP42 data (EPA 1995). Fitted distribution shown as solid line.

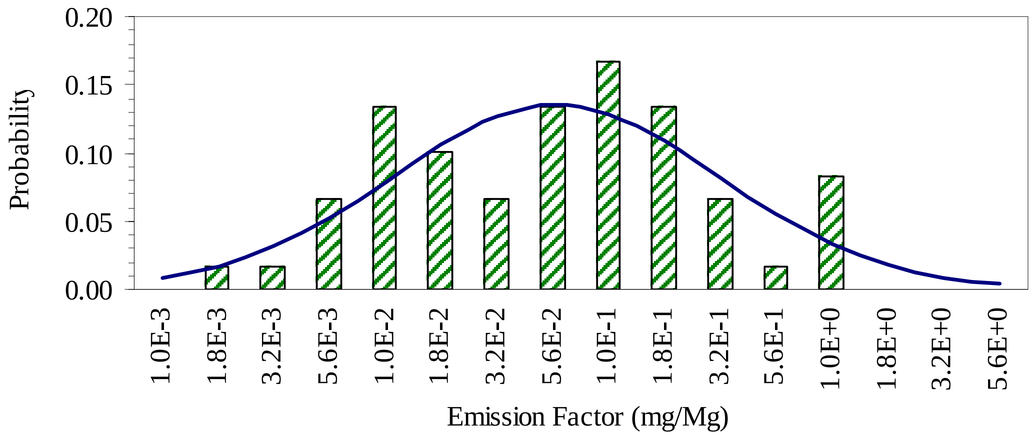


Table 8 summarizes statistics from fitting 2,3,7,8-TCDF and 2,3,7,8-TCDD to individual measurements and to the 12 facilities (the latter based using facility averages). These two compounds did show a reasonable linear relationship (though with considerable scatter). Also, it was determined that the dioxin/furan TEQ emission rate was on average 1.5 times greater than the 2,3,7,8-TCDD concentration. These data allow the determination of a distribution for dioxin/furan TEQ emission rate by the following procedure:

1. Estimate the geometric mean of TEQ emission rate as 1.5 times the geometric mean of the 2,3,7,8-TCDD data from AP-42 measurements. This may be done for individual measurements and for facilities (using the facility average).

2. Estimate the geometric standard deviation of the TEQ emission rate as the average of the geometric standard deviation of the 2,3,7,8-TCDD and 2,3,7,8-TCDF data. The standard deviation derived from the TCDF data are included as this compound is correlated with TCDD, and TCDF are found at higher levels and thus may be measured more accurately. In practice, the geometric standard deviations for TCDF are smaller than those for TCDD, meaning that higher percentile values will be more moderate.

3. Account for variability and uncertainty by estimating the TEQ emission rate at an upper percentile, e.g., 90th percentile, using the inverse log-normal distribution, the geometric mean, and the standard deviation from above. Again, this may be done for individual measurements and at the facility level.

Table 8 Statistics from fitting AP42 data for 2,3,7,8-TCDF and 2,3,7,8-TCDD emission factors (kg/Mg) from uncontrolled incinerators to lognormal distributions.

Statistic	***2,3,7,8-TCDF***		***2,3,7,8-TCDD***		***TEQ Estimates***	
	Individual Observ.	***Facility Average***	***Individual Observ.***	***Facility Average***	***Individual Observ.***	***Facility Average***
Arith. Mean	0.207	0.129	0.046	0.027	0.069	0.041
Geo. Mean	0.077	0.074	0.011	0.008	0.017	0.012
Geo. Std. Dev.	5.450	4.523	8.009	6.085	6.729	5.304
75th percentile	0.242	0.204	0.045	0.026	0.060	0.036
90th percentile	0.678	0.509	0.159	0.079	0.191	0.099
95th percentile	1.256	0.880	0.339	0.152	0.382	0.182
99th percentile	3.988	2.462	1.400	0.520	1.401	0.567

In practice, including the TCDF data and using statistics at the facility level moderates results, e.g., standard deviations are smaller. Still, the AP42 show very large standard deviations, e.g., 90th percentile values are roughly 10 times the geometric mean. It should also be noted that the AP-42 estimate is equivalent to approximately the 75th percentile. This results as the emission data are roughly lognormally distributed, and EPA's use of the arithmetic mean value gives the highest values (extrema) disproportionate influence, thus inflating the emission factor.

It is suggested that reasonable and useful estimates of emission rates for small-scale incinerators that reflect 'best practices' can be estimated from this analysis. Here we utilize the 90th percentile estimate for facility averages, namely, an emission rate of 0.1 kg TEQ/Mg. This is equivalent to a chimney gas concentration of 10 ng TEQ/Nm^3, which is within the values measured in small-scale units, though by no means the highest. This is believed to represent a reasonable value for a well-maintained, properly operated, small-scale incinerator. The major concerns affecting the usefulness of this estimate are (1) different waste types; (2) the relatively long start-up and cool-down periods of small-scale units relative to the units in the AP42 database; and (3) differences in temperature and residence times.

4.3.6 Regulatory emission limits

Regulatory limits may also be used to approximate emissions. Existing limits were shown in Table 5.

4.3.7 Emission estimates of other pollutants

As mentioned, small-scale incinerators will emit other pollutants of concern. Very few of these incinerators have been measured. Uncontrolled incinerators in AP42 are considered to reflect the magnitude of these emissions, and average of emission measurements were shown in Table 5.

4.3.8 Summary of dioxin emission estimates

The available data relevant to small-scale incinerators (without air pollution control equipment) appear to fall into three groups:

1. *Best practices*. Properly operated and maintained units utilizing sufficient temperatures, afterburners and other features that limit dioxin/furan production. A reasonably conservative estimate of the emission concentration is taken from the 90th percentile AP-42 emission factor analysis presented earlier, specifically, 10 ng TEQ/Nm^3. While conservative for the AP-42 units, however, this value may not be conservative for small brick units like the De Montfort design that have short and variable residence times (see Table 2).
2. *Expected practice*. Improperly designed, constructed, operated or maintained units that feature afterburners. Emissions from the SIMCIN, Thailand and UNDP Class 2 tests range to 600 ng TEQ/Nm^3, though most tests are lower. Using a 500 ng TEQ/Nm^3 value may be conservative, however, the available data here are admittedly scarce.
3. *Worst-case*. Incinerators without an afterburner. UNDP estimates an emission concentration of 4000 ng TEQ/Nm^3 for this simple technology.

4.4 Exposure and risk estimates

This section derives exposure and risk estimates for small-scale incinerators.

4.4.1 Methods to estimate exposures

There are multiple pathways by which humans can be exposed to dioxin emissions. For non-occupationally exposed persons, 16 pathways are considered in EPA risk guidance (Table 9). A number of simplifying assumptions are needed to handle this complexity, and minor or unlikely pathways are often deemphasized. Dispersion modeling or monitoring may be used to estimate concentrations in air and contaminants deposited to soil and plants, simplified hydrologic models account for soil and water movement and erosion, and transfer factors represent uptake among biological media.

- Assessments tend to be site-specific:
  - The composition and emission rate of pollutants vary by source.
  - Dispersion and accumulation into the environment depends on prevailing meteorology, ground cover, soil erosion rates, and other local environmental factors.
  - Land use and activities, specifically, the presence of farms and fishing, dictates the environmental pathways that must be considered.
- Uncertainties in exposure assessments are very high, thus:
  - Explicit treatment of uncertainty is strongly recommended.
  - Worst-case are used to be conservative.
  - Field monitoring program to confirm exposures and other estimates, and to establish local relationships between air emissions, concentrations in soil, foods, etc., are helpful and essential for validation purposes (Lorber et al. 1998; Sandalls et al. 1998).
- The food pathway is likely to dominate exposures, thus:
  - Locally produced food must be considered.
  - Children will have higher exposures due to different consumption behavior, e.g., more milk.

4.4.2 Previous exposure studies

Several studies have examined human exposures and risks from incinerator emissions. Most have looked at municipal or hazardous waste incinerators, which tend to be larger than medical waste incinerators. Few validation studies have been completed. As mentioned earlier, as a result of stricter emission standards for dioxins and furans in the EU and the US, releases of these substances have been significantly reduced in several countries (WHO, 1999), and concentrations in many types of food (including mother's milk) have decreased sharply (UNEP, 1999).

Domingo (2002) shows effects of decreasing stack gas concentrations emitted from a municipal solid waste incinerator in Montcada, Spain from ~10 ng TEQ/m^3 to below 0.1 ng TEQ/m^3 (air pollution control devices added included acid gas scrubbing, fabric filtration, and activated carbon) that reduced environmental exposures from 0.051 to 0.012 pg TEQ/kg-day for adults, and from 0.081 to 0.027 pg TEQ/kg-day for children, based on measured soil and plant concentrations measured 500 m from the incinerator, and modeling inhalation, dermal contact, and incidental soil and dust ingestion. Other dietary pathways were excluded as vegetables, grains, fruits, cereals and livestock were not raised in the urban area.

Table 9 Pathways of exposure considered in EPA guidance

1.	**Air → Human**	*inhalation*
2.	**Air → Soil → Human**	*deposition*; *ingestion*
3.	**Air → Above-ground Vegetable → Human**	*deposition + uptake of vapor phase*; *ingestion*
4.	**Air → Soil → Root Vegetable → Human**	*deposition*; *uptake of pore water*; *ingestion '*
5.	**Air → Soil + Above-ground Vegetable → Beef → Subsistence Farmer**	*(see above)*; *ingestion*; *ingestion*
6.	**Air → Soil + Above-ground Vegetable → Milk → Subsistence Farmer**	*(see above)*; *ingestion*; *ingestion*
7.	**Air → Waterbody → Fish → Subsistence Fisher**	*deposition + runoff + erosion*; *bioaccumulation*; *ingestion*
8.	**Air → Soil → Human**	*deposition*; *dermal contact*
9.	**Air → Surface Water → Human**	*deposition*; *ingestion*
10.	**Air → Soil → Surface Water → Human**	*deposition*; *overland flow*; *ingestion*
11.	**Air → Surface Water → Human**	*deposition*; *dermal contact*
12.	**Air → Soil → Surface Water → Human**	*deposition*; *overland flow*; *dermal contact*
13.	**Air → Surface Water → Cattle (Beef + Milk) → Farmer**	*deposition*; *ingestion*; *ingestion*
14.	**Air → Soil → Surface Water → Cattle (Beef + Milk) → Farmer**	*deposition*; *overland flow*; *ingestion*; *ingestion*
15.	**Air → Biological Media → Human**	*deposition*; *ingestion*
16.	**Air → Mother's Breast Milk → Infant**	*all inhalation, non-inhalation exposures*; *ingestion*

Bennett et al. (2002) estimates individual intake fraction or iFi for dioxin (and other compounds). The iFi is defined as that fraction of the emissions taken in by a specific individual over all exposure pathways. Thus, the iFi represents the source-to-dose transfer coefficient that accounts for dispersion, transformations, bioaccumulation, etc. Based on US data including the estimated intake of 63 pg TEQ/day (due to intake from air, vegetable fat, meat, dairy, milk, eggs, poultry, pork, fish and soil), and estimates of dioxin emissions (3 300 g TEQ), iFi = 7×10^{-12}. Based on the CalTOX model, iFi = 2.1×10^{-12}. It should be noted that these values represent a time and space average over the US, not values that might apply to a highly exposed individual (but see below).

Nouwen et al. (2001) estimated exposures near two large municipal incinerators near Antwerp, Belgium for several scenarios, including one assuming high consumption rates of locally produced foods, e.g., 25% of vegetables, 50% of meat, and 100% of milk. For this scenario, 1980 exposures with high emissions (18.9 g TEQ/yr) were 2.8 and 11.3 pg TEQ/kg-day for adults and children, respectively, most coming from milk and meat ingestion. Due to air pollution controls (lowering emissions to 3.1 g TEQ/yr), 1997 exposures were 0.73 and 2.4 pg TEQ/kg-day for adults and children, respectively. Inhalation accounted for about 1% of adult exposure, and 0.5% of child exposure. Measured soil concentrations did not correspond to predictions. From the total TEQ emissions reported in the paper, the local individual intake fraction iFi was derived, specifically, the adult iFi = 1.0×10^{-9}, and the child iFi = 1.8×10^{-8} (based on averaging estimates for 1980 and 1997). It should be noted that these values are 150 and 520 times greater than that derived by Bennett et al. (2002), but they apply for an exposed population (within ~3 km of the incinerators).

4.4.3 Dioxin intake and risks for a single incinerator – all exposure pathways

Dioxin exposures are derived using estimates of annual emissions and individual intake fractions (iFi), defined earlier as that fraction of the emissions taken in by a specific individual over all exposure pathways. The iFi derived for the Belgium study (Nouwen et al. 2001) is used as a reasonable worst-case since it represents a large fraction of locally grown food in the diet. Reasonable worst-case conditions are justified in a screening application.

It should be recognized that the iFi is pollutant- and site-specific, thus, no single value will be representative of local conditions. This suggests that site-specific modeling is necessary, or at least various representative regimes (e.g., dessert, temperate, subtropical, mountain, plan, etc.,) might be modeled. In the present case, the use of the iFi value derived from the Belgium study raises several issues:

- It is based on a relatively high consumption of meat, egg, dairy, etc., thus intake will be overestimated for populations eating primary grains.
- The relatively wet climate in Belgium increases wet deposition locally, compared to dry climates.
- The moderate stack height and flat land in Belgium will decrease air concentrations, compared to short stacks and hilly or mountainous areas, thus decreasing deposition and dose.
- It represents an average value for an impact area, but not necessarily the most exposed actual person (MEAP).
- It does not account for all pathways, e.g., fish and breast milk consumption are omitted.

Emission estimates are derived for four scenarios utilizing single small-scale incinerators:[15]

- Low usage – equivalent to 1 hr of incineration per month, 12 kg waste per month, or about 277 syringes per day.
- Medium usage – equivalent to 2 hr of incineration per week, 100 kg waste per month, or about 2308 syringes per day.
- High usage – equivalent to 2 hr of incineration per day, 700 kg waste per month, or about 1346 syringes per day.
- Universal usage of small-scale incinerators – burning 12 000 to 20 000 kg sharps waste from injections in the developing world. (In this scenario, the Bennett et al. (2002) – not the Nouwen et al. (2001) iFi – is used, as explained later.)

The emission estimates are based on 10 m^3 air per kg waste[16] and three dioxin stack gas TEQ concentrations:

---

[15] The total waste quantity is estimated assuming a De Montfort incinerator operating at capacity, 12 kg/hr. Syringe number estimates assume most waste incinerated is syringes at 100 syringes per kg waste.

[16] This flow rate may be underestimated. Some reports in larger scale facilities show flow rates of 15 m^3/kg. This would increase TEQ emissions by 50%. Also, operating the De Montfort incinerator at optimal capacity, about 6 kg/hr, would have the effect of doubling burn time, emissions and exposures.

- Best practices - 10 ng TEQ/m^3 representing a conservative estimate.
- Actual practices - 500 ng TEQ/m^3 representing a conservative estimate.
- Worst-case - 4000 ng TEQ/m^3 representing for single chamber incinerators.

The total annual doses for children and adults are estimated assuming body weights of 15 and 70 kg, respectively:

Child dose (ng TEQ/yr) = [1.8 x 10^{-8} g intake child)/(kg-yr)]/[(g emission)/yr] x [15 kg/child] x [10^9 ng/g]

Adult dose (ng TEQ/yr) = [1.0 x 10^{-9} g intake adult)/(kg-yr)]/[(g emission)/yr] x [70 kg/adult] x [10^9 ng/g]

The lifetime excess cancer risk is calculated using the US EPA upper bound cancer risk slope factor:

Child risk = [0.001 kg-day/pg] x [child/15 kg] x [year/365 days] x [Child dose ng/yr] x [1000 pg/ng]

Adult risk = [0.001 kg-day/pg] x [child/70 kg] x [year/365 days] x [Adult dose ng/yr] x [1000 pg/ng]

Results are calculated for both children and adults, and compared to the WHO provisional values of acceptable intake in Table 10. In the medium usage scenario, for example, childhood exposures for well to poorly controlled incinerators represent 0.02 to 12% of WHO's provisional intake value, and lifetime cancer risks from 4 x 10^{-7} to 2 x 10^{-4}. To properly interpret these results, the following should be recognized:

- Predicted exposures and risks portray those experienced by the local community that consumes locally produced food. Within this group, the exposures and risks do not necessarily reflect the maximum expected, but instead reflect an average for individuals living within several km of the incinerator.
- Children are predicted to have higher exposures (doses) than adults, a consequence of different iFi values that reflect differences in diets and exposure patterns.
- The WHO provisional value represents a total intake level that includes all sources of exposure. Further, because the actual current exposures in most countries is unknown, and that current exposures already represent a significant fraction of WHO provisional values (e.g., an average of 24 ng TEQ/year in the US, nearly half of the provisional intake value), a source contributing more than a small fraction (perhaps 1%) of the provisional value may be significant.
- While the selection of a particular quantitative level for "acceptable risks" is context-specific and always involves an arbitrary component, risks to public health from environmental agents that exceed 10^{-4} to 10^{-6} are often viewed as unacceptable.[17]
- Risks due to occupational exposures and contact with ash are not included.

Table 10 Dioxin (TEQ) intakes and risks for an individual incinerator under three usage scenarios and three emission conditions.

[17] An acceptable risk level depends on many factors, e.g., the number of people exposed, the nature and consequence of the exposure, ability to taken defensive actions, etc. As examples, the US Clean Air Amendments specify a risk level of 10^{-6} in regulating air toxics. The US Superfund program uses a 10^{-4} risk to define an imminent hazard requiring cleanup. Other criteria may be considered, e.g., the probability of an adverse event, the number of people at risk, and the nature of harm.

Scen-ario	Burn Frequency (times/yr)	Burn Period (hr/burn)	Waste (kg/year)	Stack TEQ Conc. (ng/m3)	Air flow (m3/kg)	TEQ Emissions (g/yr)	Total Dose Child (ng/yr)	Total Dose Adult (ng/yr)	Ratio to WHO ADI Child (%)	Ratio to WHO ADI Adult (%)	EPA Cancer Risk Child (prob)	EPA Cancer Risk Adult (prob)
Low usage - equivalent to 1 hour of incineration per month												
	12	1	144	10	10	0.00001	0.0003	0.0000	0.002	0.000	4.7E-8	5.9E-10
	12	1	144	500	10	0.00072	0.0130	0.0008	0.125	0.002	2.4E-6	2.9E-8
	12	1	144	4000	10	0.00576	0.1038	0.0060	0.998	0.012	1.9E-5	2.4E-7
Medium usage - equivalent to 2 hours of incineration per week												
	50	2	1200	10	10	0.00012	0.0022	0.0001	0.021	0.000	4.0E-7	4.9E-9
	50	2	1200	500	10	0.00600	0.1082	0.0063	1.040	0.013	2.0E-5	2.4E-7
	50	2	1200	4000	10	0.04800	0.8653	0.0501	8.320	0.103	1.6E-4	2.0E-6
High usage - equivalent to 2 hours of incineration per day												
	350	2	8400	10	10	0.00084	0.0151	0.0009	0.146	0.002	2.8E-6	3.4E-8
	350	2	8400	500	10	0.04200	0.7571	0.0438	7.280	0.090	1.4E-4	1.7E-6
	350	2	8400	4000	10	0.33600	6.0569	0.3505	58.239	0.723	1.1E-3	1.4E-5

Results in Table 10 are interpreted for the three emission conditions:

- Best practice (10 ng TEQ/m^3 emission rate): Incinerator emissions at any usage level represent well below 1% of the WHO provisional intake value for children and adults. Cancer risks do exceed 10^{-6} risk in the case of high usage.
- Expected practice (500 ng TEQ/m^3): Only the low usage scenario keeps the intake to a small fraction of the WHO provisional intake, although again the 10^{-6} risk level is exceeded.
- Worst-case emissions (4000 ng TEQ/m^3): Even under low usage rates, intake and risks may be unacceptable.

4.4.4 Dioxin intake and risks for widespread use of incinerator

This section expands the scenario to consider the use of small-scale incinerators for much of the sharps waste in developing countries, roughly 1.2 billion injections per year producing 12 000 to 20 000 tons of waste per year (discussed earlier in Section 3). This scenario has the advantage of obtaining a more representative estimate of exposure as this scenario relaxes the site-specific assumptions implied using the intake fraction estimated for a single environment. In this case, the adult intake fraction iFi = 7 x 10^{-12}, as taken from Bennett et al. (2002). No comparable child value is available, thus as a preliminary estimate, the child iFi is increased by 17 times, reflecting predictions by Nouwen et al. (2001). While the accuracy of the adult iFi is considered fair, the extrapolation for the child value is less certain. The specific assumptions for this scenario are:

- All sharps resulting from vaccination campaigns are incinerated using small-scale incinerators
- The individual intake fraction derived for adults in the US is relevant to local conditions
- The individual intake fraction for children can be adjusted by factors derived from Nouwen et al. (2001).
- Dioxin emissions occur over the continental scale

Somewhat surprising, exposures and risks resulting from widespread use of incinerators (Table 11) are similar to that obtained for a single unit. Under the best practices case, aggregate incinerator emissions range between 1 and 2 g TEQ/year, and the resulting exposures represent well below 1% of the provision WHO value, though some risks exceed 10^{-6}. Under actual practices to worst-case emissions, between 60 and 800 g TEQ/year are emitted, adult exposures range from 1 to 12% of the WHO provisional value, and risks are in the 10^{-5} to 10^{-4} range. Child levels are higher by 17 times. Overall, only with emissions at the lowest level, reflecting best practices, are exposures and risks small.

Table 11 Dioxin (TEQ) intakes and risks for widespread use of incinerators under three emission conditions.

Waste Estimate	Waste (kg/year)	Stack TEQ Conc. (ng/m3)	Air flow (m3/kg)	TEQ Emissions (g/yr)	Total Dose Child (ng/yr)	Total Dose Adult (ng/yr)	Ratio to WHO ADI Child (%)	Ratio to WHO ADI Adult (%)	EPA Cancer Risk Child (prob)	EPA Cancer Risk Adult (prob)
Lower range										
	1.2E+7	10	10	1	0.145	0.008	0.08	0.02	2.7E-5	3.3E-7
	1.2E+7	500	10	60	7.257	0.420	4.04	0.87	1.3E-3	1.6E-5
	1.2E+7	4000	10	480	58.060	3.360	32.31	6.93	1.1E-2	1.3E-4
Upper range										
	2.0E+7	10	10	2	0.242	0.014	0.13	0.03	4.4E-5	5.5E-7
	2.0E+7	500	10	100	12.096	0.700	6.73	1.44	2.2E-3	2.7E-5
	2.0E+7	4000	10	800	96.766	5.600	53.85	11.55	1.8E-2	2.2E-4

4.4.5 Dioxin intake and risks for a single incinerator from inhalation only

Ambient air concentrations are estimated using dispersion modeling, in particular, screening-level models to estimate worst-case concentrations. This purpose of this modeling is to estimate maximum exposures that might occur to workers or others very close to the incinerator, and to assess the effect of stack height on these exposures.

The US EPA Screen3 model, a Gaussian plume model, is used to estimate ambient air concentrations within 5 km of the incinerator. Predictions from the model represent a 1-hour average concentrations at breathing height (2 m), directly downwind. Concentrations are a function of the source parameters (Table 12) and meteorological parameters.

Gaussian plume models have several limitations. First, these models typically are used for downwind distances from 0.1 km to about 100 km. Results outside this distance range require careful interpretation. Second, these models cannot be used to predict dispersion in calms (winds less than 1 m/s). (In most open locations, calms occur no more than roughly 1 – 5% per year.) Third, these models are not applicable to dispersion within forests, in very hilly complex terrain, or elsewhere where the assumption of a generally uniform wind field is not valid.

Key source parameters for modeling a typical De Montfort type incinerator are listed in Table 12. It should be noted that these parameters also will vary among sites, e.g., some facilities may have higher stacks. Also, several parameters will vary over the operating (burn) cycle, e.g., emission rates, stack gas temperatures and exit velocities.

Meteorology is site and time specific. The Screen3 model is used to estimate worst-case concentrations over a range of meteorological scenarios, and in particular, the sensitivity to stability class and stack height.[18]

[18] Generally, to estimate long-term concentrations relevant to chronic exposures, multiple years of hourly site-specific meteorological data are needed to obtain a representative predictions from a simulation model.

Table 12 Parameters for dispersion modeling.

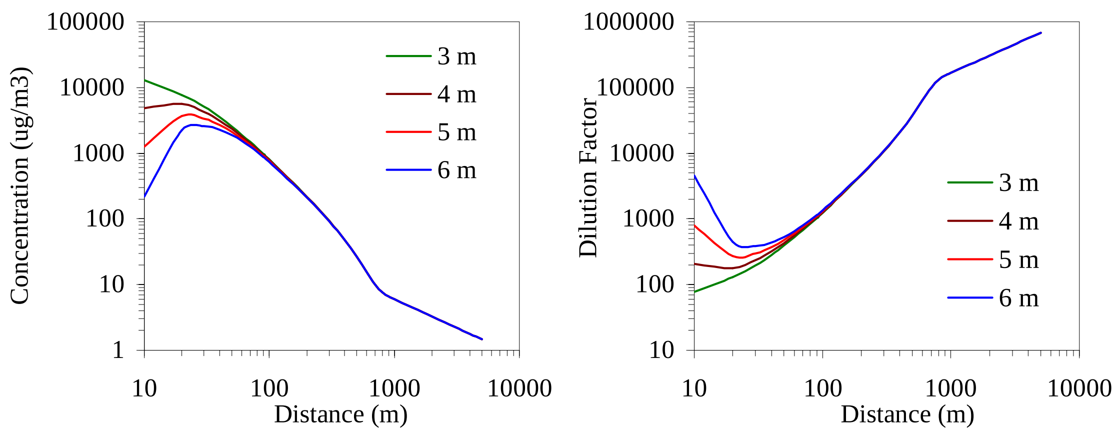
Parameters	***Nominal Value***	***Range***	***Justification***
Model	Screen3	-	Simple Gaussian plume model
Emission rate	1 g/s	(adjusted as needed)	Nominal value selected for convenience
Stack/chimney height	4 m	3 – 6	
Stack/chimney diameter	0.12 m	-	
Stack/chimney exit temp.	450 C / 723 K	400 – 700 C	
Stack/chimney exit velocity	4 m/s	2 – 7 m/s	
Downwind distances	> 100 m	10 – 5000 m	Results at <100 m are highly uncertain

Figure 10 shows sensitivity to stack (chimney) height for three stability classes, representing a wide range of meteorological conditions from unstable (sunny, low winds) to neutral (higher winds) to very stable (night, clear skies, low winds). Model results indicate the following:

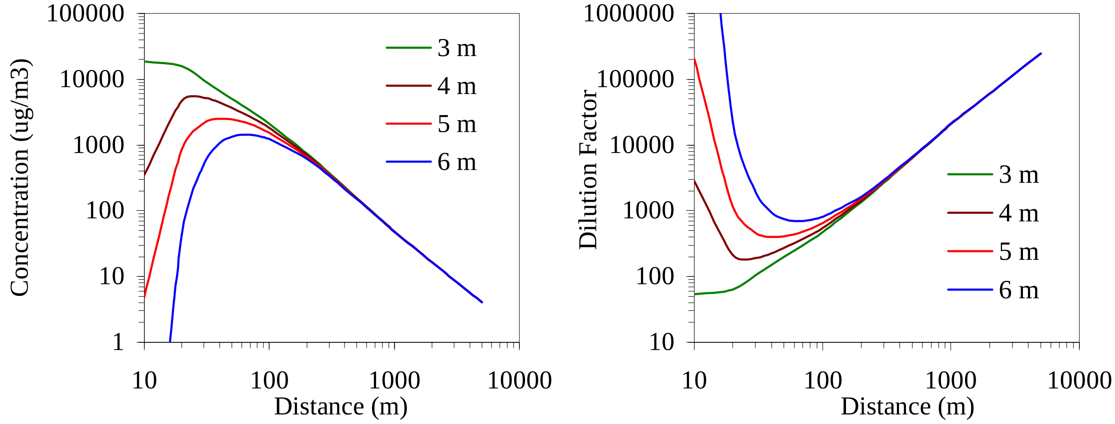
- Plume rise for the modeled source is negligible (about 1 m). Even this may be overestimated since most small-scale incinerators have a rain shield that horizontally disperses the plume with the effect of reducing plume rise. The rain shield would have the effect of increasing concentrations, but the effect is minor.
- Maximum concentrations are produced at downwind distances from 0 to 800 m, with distances increasing under stable conditions. During the day (neutral and unstable conditions), maximum concentrations are produced within 100 m.

Figure 10 Dispersion model results showing sensitivity to chimney heights from 3 to 6 m and stability classes A, D and F.
Left panel shows breathing height concentrations for a 1 g/s emission rate. Right panel shows dilution ratio. Modeled source uses nominal parameters (stack dia = 0.12 m, gas temp = 723 K).

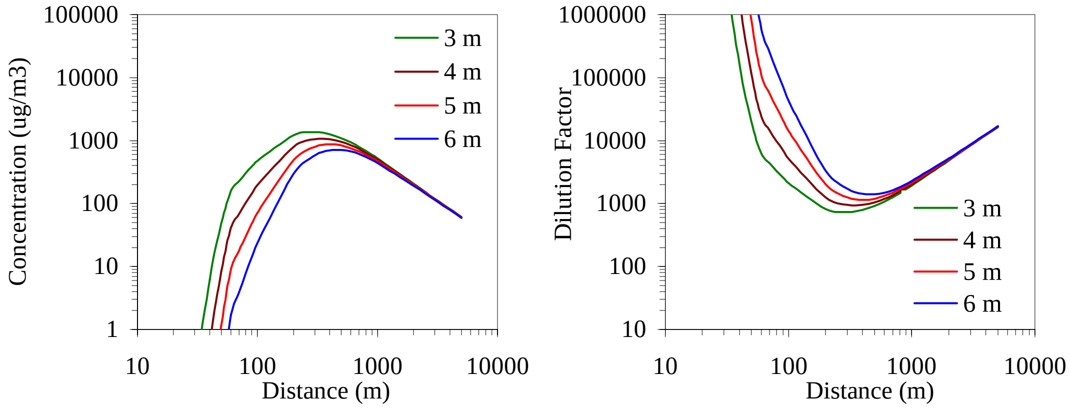
Stability class A (stable, U = 1 m/s)



Stability class D (neutral, U = 3 m/s)



Stability class F (stable, U = 1 m/s)



- Increasing stack height from 3 to 6 m significantly lowers concentrations by 5 to 13 times during daytime, and the major effect is observed close to the source (relevant for operators). Higher stack heights decrease concentrations at nighttime near the source, but differences at distances over 200 m are negligible.
- Dilution ratios below 1000 occur at distances below 100 m for daytime conditions, regardless of stack height. At night, dilution ratios below 1000 can occur only with the shortest stack height (3 m) and from distances from 200 to 500 m.
- Dilution ratios below 200 occur at distances up to 30 to 50 m for day time conditions for short-stack heights (3 – 4 m).

To couple these results to exposures, a number of simplifying assumptions are made that equate to the maximum exposed individual (MEI), a hypothetical scenario that results in exaggerated exposure:

- Waste is burned under 3 scenarios (low, medium, high usage) and under 3 emission conditions, as discussed earlier.
- The dilution ratio is 1000.
- A person inhales air directly downwind of the incinerator for each hour that it is operating at a rate of 0.32 or 0.83 m^3/hr, child and adults, respectively.

Results are shown in Table 13. Because the MEI scenario is extreme and unrealistic, the interpretation differs from that used previously. In reality, individuals will not be downwind 100% of the time that the facility is operating. Accounting for the variability of wind directions and the mobility of individuals, a person is not likely to be directly downwind of the incinerator and within the plume more than about 10% of the time.[19] This would have the effect of decreasing exposures by 10-fold. With this interpretation, only low and medium usages under the best practices emissions give exposures below 1% of the provision WHO limit.

Table 13 Maximum inhalation exposures to children and adults assuming a dilution ratio of 1000.

Scen-ario	Burn Frequency (times/yr)	Burn Period (hr/burn)	Waste (kg/year)	Stack TEQ Conc. (ng/m3)	Air flow (m3/kg)	TEQ Emissions (g/yr)	Inhalation Dose Only Child (ng/yr)	Inhalation Dose Only Adult (ng/yr)	Ratio to WHO ADI Child (%)	Ratio to WHO ADI Adult (%)	EPA Cancer Risk Child (prob)	EPA Cancer Risk Adult (prob)
Low usage - equivalent to 1 hour of incineration per month												
	12	1	144	10	10	0.00001	0.03	0.08	0.3	0.2	5.2E-6	2.9E-6
	12	1	144	500	10	0.00072	1.43	3.75	13.7	7.7	2.6E-4	1.5E-4
	12	1	144	4000	10	0.00576	11.40	30.00	109.6	61.9	2.1E-3	1.2E-3
Medium usage - equivalent to 2 hours of incineration per week												
	50	2	1200	10	10	0.00012	0.24	0.63	2.3	1.3	4.3E-5	2.4E-5
	50	2	1200	500	10	0.00600	11.88	31.25	114.2	64.4	2.2E-3	1.2E-3
	50	2	1200	4000	10	0.04800	95.00	250.00	913.5	515.5	1.7E-2	9.8E-3
High usage - equivalent to 2 hours of incineration per day												
	350	2	8400	10	10	0.00084	1.66	4.38	16.0	9.0	3.0E-4	1.7E-4
	350	2	8400	500	10	0.04200	83.13	218.75	799.3	451.0	1.5E-2	8.6E-3
	350	2	8400	4000	10	0.33600	665.00	1750.00	6394.2	3608.2	1.2E-1	6.8E-2

4.5 Uncertainty

As highlighted earlier, screening level (and all other types of) risk assessments involve considerable uncertainty. This applies to estimates of needle infection rates from unsterilized sharps, cancer rates due to dioxin exposures, and many other aspects. Still, the technical exercise of estimating exposures and risks is a useful input in decision- and policy-making. Assessments should define the range of technically feasible possibilities, identify major uncertainties, provide reasonable upper and lower bounds, interpret the results, highlight issues and uncertainties, and if necessary, stimulate further work to provide the necessary and appropriate information.

This report used screening analyses for the purpose of examining emissions, exposures and risks associated with dioxin and furans. The screening level analysis utilized a number of conservative assumptions, in part due to large uncertainties and data gaps. In particular, exposure estimates would be improved by:

- Better emission data.
- Information describing current dioxin exposures, both to validate the models as well as to indicate current background exposure levels.
- Analyses in which the most probable exposures and risks are estimated for occupational and local populations, in addition to most exposed populations.

[19] In some applications, Screen3 predictions of maximum hourly concentrations are adjusted to maximum 24 hour concentration averages by multiplying by 0.08. While simplified box and other models may be used, simulation modeling using site-specific and hourly meteorology is necessary to obtain long term (annual average) predictions of concentrations and exposures.

The analysis excluded a number of issues

- Occupational risks. Although not quantified, incinerator operators may receive the highest exposures and risks of any group exposed to incinerator emissions. At present, this is based on largely anecdotal evidence that indicates potential for excessive exposures, including:
    - Surveys indicating that operator training is deficient.
    - Improper use of personal protective equipment.
    - Exposure to 'fugitive' emissions when charging units with waste and fuel.
    - Exposure when raking grates and disposing of ash.
- Effects of other pollutants. In particular, incinerator emissions of heavy metals and particulate matter may be sufficiently large to raise health concerns.
- Additional exposure pathways, e.g., maternal breast milk to infant, local fish consumption, etc.
- Secondary impacts resulting from technological choices. For example,
    - Incineration may discourage waste segregation and waste reduction efforts.
    - Ash and other waste disposal options may become a secondary concern.
    - Possible shortages of fuel/firewood in some situations.

5 Transitioning countries to safe health-care waste treatment options

Without appropriate management and treatment, infectious health-care waste has the potential to cause a significant disease burden (estimates of Hepatitis B, C and HIV infections and deaths due to reused and contaminated syringes were presented earlier). Safe and effective waste treatment options such as autoclaving are increasing in availability and decreasing in cost, and costs appear competitive with small-scale medical waste incinerators (Wright et al., 2001). Transporting such wastes to a regional facility, where available, would be another option. Other options, such as melting or encapsulation, may be simpler and cheaper.

Can the use of incineration be justified as a transitional or interim technology to effectively and safely disposing of healthcare wastes useful in certain situations? This section briefly mentions several possibilities.

- Remote settings where very small quantities of waste are generated in areas with poor infrastructure and ability for training, oversight, etc. Investments and resources dedicated to incineration (construction, training, etc.) in such situations do not appear warranted given the option to either collect and transport waste to a suitable facility, or to use possible on-site disposal options that are inexpensive and relatively safe, e.g., disinfection, encapsulation.
- Emergency uses when large quantities of infectious waste are generated. This could include major planned (routine) or emergency vaccination campaigns. Here, relatively large quantities of waste might be generated, but generally only in areas with larger populations. However, current small-scale units should not be sited in populated areas, construction and training will take some time, and emergency waste quantities might be absorbed by scaling up (safer) methods used for routine disposal of infectious waste.

5.1 Implementation Schedule

The schedule to develop and implement safer health-care waste options should consider the nature of exposures. Community health risks due to incinerator emissions may be classified into acute and chronic exposures and effects.

- Chronic exposures/effects: Chronic exposure to persistent pollutants like dioxins, furans, and other persistent pollutants is believed to present the most serious health risk. For communities living and working near small-scale incinerators, exposures accumulate from several to many years of incinerator operation. Over this time, pollutants may accumulate in the environment and migrate into the food web. Such exposures are judged to be potentially serious and may affect a large population living or obtaining food within several kilometers of incinerators, especially larger and poorly controlled units.
- Acute exposures/effects. Acute exposure to particulate matter, acid gases, and other pollutants may result from repeated short-term (several to many hours per month) inhalation exposures for individuals living within 500 to 750 m of the incinerator. For these exposures to occur, individuals would need to be downwind, at least occasionally. Such exposures may be associated with adverse respiratory and other health effects. Given poor operation, low chimney heights, and nearby communities, single exposures will certainly happen, but repeated events would normally be judged to be uncommon. However, repeated exposure events may occur if prevailing winds are persistent and tend to "channel" the plume over the same populated areas, or the incinerator is in the midst of a populated area. (Ideally, such situations would be avoided by proper siting.)

Chronic exposures to dioxins/furans and other pollutants are judged to pose the major health risk. While means to reduce exposures by utilizing safer treatment options should be undertaken in an expeditious manner, transitioning to safer (non-polluting) options over a several year period would not be expected to result in significant adverse consequences.

6 Conclusions

This report has drawn the following conclusions regarding low cost small-scale incineration technology as currently practiced:

- Properly designed and operated dual-chamber controlled-air small-scale incinerators represent an improvement over uncontrolled drum or pit burning practices. Operator training, certification, unit permitting and inspection are necessary to minimize emissions and risks.
- Numerous design, construction, siting, operational and management deficiencies result in poor performance. Based on available surveys, such deficiencies are common, not the exception.
- Small-scale units cannot meet modern emission standards.
  - Improved operation, process monitoring, and emission controls will be necessary to meet standards for dioxin, furans, hydrogen chloride, particulate matter, several metals, etc. These changes will be expensive (costs will increase by an order of magnitude).
  - A monitoring and permitting program is required to ensure that emissions standards are effective.
- Incinerator emissions of both conventional (e.g., particulate matter) and toxic pollutants (e.g., dioxin/furans) may pose risks that potentially affect:
  - Waste workers and incinerator operators.
  - Local communities through both inhalation exposure and through the consumption of locally-produced food that becomes contaminated from incinerator emissions.
  - Regional/global environment, through the discharge of toxic and persistent chemicals.
- Based on available data and estimates, dioxin/furan emissions from units operated infrequently and under best practices would not produce excessive exposures and risks, however, the feasibility of achieving and sustaining best practices seems doubtful.
- The exposure and risk assessment has many uncertainties, data gaps are very large, and consequently a wide range of results is presented.
- Incineration of health-care waste producing relatively high emissions of persistent compounds will controvert Stockholm Convention aimed at elimination of these compounds.
- The availability of incineration may negatively affect the development and use of preferred waste treatment options.
- WHO should not develop an emission limit for small-scale incinerators, but should view incineration as a transitional means of health-care waste disposal.

While not researched extensively in this report, the cost-effectiveness of incineration does not appear to be favorable over autoclaving in developed countries. Several low cost non-incineration technologies suitable for small quantities of waste in remote areas are being demonstrated. These are worthy of further investigation and support.

7 References

Adama S. 2003. Results of Waste Management in Africa 2003, presentation at the Safari Park Hotel, 18-20 Sept. 2003.

Bennett, DH, MD Margni, TE McKone, O Jolliet, 2002, Intake Fraction for Multimedia Pollutants: A tool for life cycle analysis and comparative risk assessment, *Risk Analysis*, 22, 5, 905-18.

Brna, T.G., and J.D. Kilgroe, 1989, Control of PCDD/PCDF Emissions from Municipal Waste Combustion Systems. Presented at the Ninth International Symposium on Chlorinated Dioxins and Related Compounds, Toronto, Canada, September 17-22.

CDC, 1997. Recommendations for follow-up of health-care workers after occupational exposure to hepatitis C virus. Centers for Disease Control, *MMWR* 1997; 46(26); 603-606.

CEC. 2000. Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the Incineration of Waste. Official Journal of the European Communities, L 332/91. Commission of the European Communities, Brussels.

Chen J, M Wey M, Z Liu Z. 2001. Adsorption mechanism of heavy metals on sorbents during incineration. *J Envir Eng* 126, 63–69.

Cudhay JJ, RW Helsel. 2000. Removal of products of incomplete combustion with carbon. *Waste Management*, 20, 339 –345.

Domingo JL, MC Agramunt, M Nadal, M Schuhmacher, J Corbella. 2002. Health risk assessment of PCDD/PCDF exposure for the population living in the vicinity of a municipal waste incinerator, Archives of Environmental Contamination and Toxicology, 43, 461-5.

EN 1948. 1996. European standard: stationary source emissions—determination of the mass concentration of PCDD/PCDFs.

EPA. 1990. Handbook, Operation and Maintenance of Hospital Medical Waste Incinerators, EPA/625/6-89/024, Office of Air Quality Planning and Standards, US Environmental Protection Agency, Research Triangle Park, NC.

EPA. 1993. Emission Factor Documentation For Ap-42 Section 2.6 Medical Waste Incineration, Office of Air Quality Planning and Standards, Office of Air and Radiation, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, June.

EPA. 1995. AP-42, Emission Factors for Medical Waste Incineration, Section 2.3, U.S. Environmental Protection Agency, Washington, DC.

EPA. 1996. Emission Factors for Medical Waste Incinerators (MWI's), EPA Contract No. 68-01-0115, ESD Project No. 89/02, MRI Project No. 6504-08, memo from David Randall, Brian Hardee to US EPA, April 8.

EPA. 1997. 40 CFR Part 60 Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Hospital/Medical/Infectious Waste Incinerators; Final Rule 48348 Federal Register / Vol. 62, No. 178, September 15.

EPA. 2001. Part I: Estimating Exposure to Dioxin-Like Compounds, and Part II.Health Assessment for 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD)and Related Compounds, US EPA Environmental Protection Agency, Office of Research and Development, Washington, DC.

EPA. 2003. Framework for Cumulative Risk Assessment, External review draft, EPA/630/P-02/001A, Risk Assessment Forum, U.S. Environmental Protection Agency, Washington, DC 20460. April 23.

FAO/WHO. 2001. *Joint FAO/WHO Expert Committee on Food Additives, Fifty-seventh meeting, Rome, 5-14 June 2001. Summary and Conclusions*. Food and Agriculture Organization of the United Nations and the World Health Organization. (http://www.who.int/pcs/jecfa/Summaries.htm).

Ferraz, M, CM Alvim; SAV Afonso. 2003. Dioxin emission factors for the incineration of different medical waste types, *Archives of Environmental Contamination and Toxicology*, 44, 4, 460-6.

Ficarella A, D Laforgia D. 2000. Numerical simulation of flow-field and dioxins chemistry for incineration plants and experimental investigation. *Waste Management* 20, 27–49

Fritsky KJ, JH Kumm, M Wilken. 2001. Combined PCDD/F Destruction and Particulate Control in a Baghouse: Experience with a Catalytic Filter System at a Medical Waste Incineration Plant, J. Air and Waste Management Association, 51:1642-1649.

Gumodoka B, et al. 1996. Injection practices in Mwanza Region, Tanzania: prescriptions, patient demand and sterility. *Tropical medicine and international health*, 1:874-880.

Hauri A, Armstrong G, Hutin YJF. 2004. Contaminated injections in health care settings. In: Ezzati, Lopez, Rodgers, Vander Hoorn, Murray. *Comparative quantification of health risks : global and regional burden of disease attributable to selected major risk factors.* WHO, Geneva, 2004 (in press).

HCWH. 2001. *Non-Incineration Medical Waste Treatment Technologies, A Resource for Hospital Administrators, Facility Managers, Health Care Professionals, Environmental Advocates, and Community Members*, Health Care Without Harm, Washington, August http://www.noharm.org/library/docs/Non-Incineration_Medical_Waste_Treatment_Te_2.pdf

HCWH. 2002. Environmentally Responsible Management of Health Care Waste With a Focus on Immunization Waste, Working Draft, Health Care Without Harm, Washington, Oct.

HCWH. 2003. Demonstrations and Pilot Testing of Non-Incineration Treatment Technologies For Rural Areas, status report, Health Care Without Harm, 1755 S Street, NW, Suite 6B, Washington, DC 20009, September.

Huang, H, A Bueckens. 1996. De Novo Synthesis of Polychlorinated Dibenzo-p-dioxins and Dibenzofurans – Proposal of a Mechanistic Scheme, *The Science of the Total Environment*, 93, 121-141.

IARC. 1997. Polychlorinated dibenzo-para-dioxins and polychlorinated dibenzofurans. Summary of data reported and evaluation. IARC Monographs, vol 69, IARC Press, Lyon

Kentucky. 1996. Medical Waste Incinerators Regulatory Manual, Kentucky Pollution Prevention Center, www.kppc.net/Publications/Training%20Manuals/mediwaste/mediwaste3.cfm.

Kezaala R. 2002. *Injection waste management in immunization campaigns: Lessons and orientations for 2002*. Unpublished WHO document presented at The Annual Meeting of EPI Managers, West Africa Block, Lomé, 20-23 March, 2002. Harare, World Health Organization Regional Office for Africa, Harare, Zimbabwe.

Lee CC, GL Huffman. 1996. Review: Medical Waste Management: Incineration. *J. of Hazardous Materials*, 48, 1-30.

Lorber, M, P Pinksy, P Gehring, C Braverman, D Winters, W Sovocool. 1998. Relationships between dioxins in soil, air, ash, and emissions from a municipal solid waste incinerator emitting large amounts of dioxins. *Chemosphere*, 37, 9-12, 2173-2197.

McKone, T, K Hammond. 2000. Managing the health impacts of waste incineration, *Environmental Science and Technology*, 34, 17, A380-7.

Miller MA, E Pisani. 1999. The cost of unsafe injections. *Bulletin of the World Health Organization*, 77(10):808-811.

Nouwen J, C Cornelis, R De Fre, M Wevers, P Vaene, C Mensink, J Patyn, L Vershaeve, R Hooghe, A Maes, M Collier, G Schoeters, R Van Cleuvenbergen, P Geuzens. 2001. Health risk assessment of dioxin emissions from municipal waste incinerators: the Neerlandquarter (Wilrijk, Belgium) *Chemosphere*, 43, 909-923.

NRC. 1999. Waste Incineration and Public Health; Report of the Committee on Health Effects of Waste Incineration; National Research Council, National Academy Press: Washington, DC, 1999.

Oka, K. 2002. Risk evaluation of dioxin emissions by incineration of syringes and needles, EC Corp., Tokyo Japan.

Parzefall, W. 2002. Risk assessment of dioxin contamination in human food: Review, *Food and Chemical Toxicology*, 40, 1185-1189.

Prüss A, E Giroult, P Rushbrook. 1999. Safe Management of Wastes from Healthcare Activities, WHO, Geneva, also http://www.who.int/water_sanitation_health/medicalwaste/wastemanag/en/

Rossi M, T Schettler. 2000. PVC & Healthcare. In: *Setting Healthcare's Environmental Agenda: Papers and Proceedings from the October 16, 2000 Conference in San Francisco, California, USA.* Health Care Without Harm, Falls Church, Virginia, USA.

Sandalls J, B Berryman, L Bennett, S. Newstead, A Fox, 1998. PCDD/PCDF on land around an industrial site and identification of source. *Chemosphere*, 37, 9-12, 2225-2237.

Seeff LB, Wright EC, Zimmerman HJ, Alter HJ, Dietz AA, and Felsher BF. 1978. Type B hepatitis after needle-stick exposure: prevention with hepatitis B immune globulin. Final report of the Veterans Administration Cooperative Study. *Ann Intern Med* 1978; 88:285-93.

Simonson L, A Kane, J Lloyd, M Zaffran, M Kane. 1999. Unsafe injections in the developing world and transmission of bloodborne pathogens: a review. *Bulletin of the World Health Organization*, 77(10):789-800.

Snary C. 2002. Health risk assessment for planned waste incinerators: Getting the right science and the science right, *Risk Analysis*, 22, 6, 1095-1105

Stanmore, BR, C Clunies-Ross. 2000. An empirical model for the de novo formation of PCDD/F in medical waste incinerators, *Environmental Science & Technology*, 34 no21:4538-44.

Taylor E. 2003. Rapid Assessment of Small-scale Incinerators: Kenya, Final Draft, July.

Travis CC. HA Hattemer-Frey. 1989. A perspective on dioxin emissions from municipal solid waste incinerators, *Risk Analysis*, 9, 91-7.

UNDP. 2003. Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases, United Nations Environment Programme, UNEP Chemicals, Geneva, Switzerland (http://www.pops.int/documents/guidance/Toolkit_2003.pdf)

UNEP. 1999. Dioxin and Furan Inventories, National and Regional Emissions of PCDD/PCDF. United Nations Environment Programme, Geneva.

WHO. 1996. Guidelines for drinking-water quality. Vol. 2., second edition. Health criteria and other supporting information.

WHO. 1999. Dioxins and their effects on human health, Fact Sheet No. 225, June 1999. World Health Organization Geneva, WHO Bulletin October 1999. (http://www.who.int/inf-fs/en/fact225.html).

WHO. 1999. Safety of Injections. WHO-UNICEF-UNFPA joint statement on the use of auto-disable syringes in immunization services, WHO/V&B/99.25, World Health Organization, Geneva.

WHO. 2001. Chapter 5.11, Polychlorinated dibenzodioxins and dibenzofurans, in: *Air Quality Guidelines for Europe 2000* (European Series, No. 91). WHO Regional Office for Europe, Copenhagen.

Wright, JC, P Millichamp, SJ Buckland. 2001. The cost-effectiveness of reductions in dioxin emissions to air from selected sources: economic analysis for section 32 of the Resource Management Act. Ministry for the Environment, Wellington.

8 Acknowledgements

Acknowledgements:

The author gratefully acknowledges permission to use photographs or graphics by Health Care without Harm, WHO, and Wel Labs.

9 Appendix A. Brochure Soliciting Input

The following was distributed October 2003 distributed to participants in Fogarty International Center meetings in Zambia and Durban. Several responses were received. Another possible venue for distribution is the World Environmental Congress in Durban, South Africa (February 2004).

Small-scale Medical Waste Incinerators:

Evaluation of Risks and Best Management Practices

SPECIAL REQUEST TO FOGARTY PARTICIPANTS & OTHERS

PLEASE FEEL FREE TO DISTRIBUTE TO POTENTIALLY INTERESTED PARTIES

Problem statement: Improper disposal of medical wastes, especially contaminated sharps (syringes and needles) that are scavenged and reused, may lead to significant numbers of hepatitis B, hepatitis C, HIV and possibly other infections. Options for safe waste disposal in developing countries are often limited. Recent designs for low-cost small-scale incinerators promise effective sterilization of medical waste, and these units have been constructed and may be suitable in certain settings. However, combustion of plastics and other materials containing polyvinyl chloride results in emissions of dioxins, furans, and other air pollutants that are toxic, persistent in the environment, and bio-accumulative. Conventional pollutants, e.g., sulfur and nitrogen oxides, are also emitted. These emissions may pose chronic risks, e.g., cancer, and possibly acute risks. There is a need to assess the risks attributable to toxic emissions of small-scale incinerators, to effectively communicate these risks to managers and policy makers involved with medical waste management, and to document "best management practices" to minimize risks should incinerators be used.

Scope of work. The World Health Organization (Department of Protection of the Human Environment) and the University of Michigan (Prof. Stuart Batterman) are undertaking a short-term investigation to characterize risks attributable to small-scale medical waste incineration and to document best management practices. This work needs to be completed in early 2004.

Opportunities to participate. A special invitation is extended for participation in this study. There are three opportunities:

1. We will be utilizing an *external review panel* to help ensure project relevance and to assess project outcomes. This panel is envisioned to provide two major functions: (a) Review of project approach in November 2003; and (b) Review of project draft reports in early 2004
2. You may have a *particular case study* that could be analyzed, e.g., an existing or potential site where medical waste incineration or other disposal practices are proposed or are taking place.
3. This project would make an *ideal research project* for a Fogarty Scholar -- if a candidate can be identified very quickly.

Your participation in topics 1, 2 or 3 – especially in the review panel – is most welcome. You are also invited to share this information with others that might be helpful and willing panelists.

For further information. Please contact (email is fine):

Prof. Stuart Batterman
The University Of Michigan
School Of Public Health
Department Of Environmental Health Sciences
2512 SPH-I, 109 Observatory Drive, Ann Arbor, Michigan 48109-2029
Tel: 734/763-2417 Fax: 734/764-9424 Email: STUARTB@UMICH.EDU

10 Appendix B. Sources of Information on Small-scale Incinerators

10.1 Westland Incinerator Corp.

See: Liem, Albert J, R. Milner, J. Scoffield, A. Chhibber, undated, Development of a Small-Scale, Simple and Robust Medical Waste Incineration System, Alberta Research Council, Vegreville, Alberta, Canada, Westland Incinerator Co., Ltd., Edmonton, Alberta, Canada.

This short (3 p) paper describes the design, commissioning and performance testing of a small-scale manually batch fed incineration system (50 kg/h over 8-h operation). The system uses a dual-chamber design, operated under starved-air conditions in the primary chamber, and a venturi scrubber. It has been tested for air emissions by an unspecified "independent and qualified consultant". Testing showed CO emissions of ~3 ppm corresponding to combustion efficiencies >99.99%, and compliance with HCl, NOx, SO_2, and PM regulations for incinerators from India, Canada (Council of the Ministers of Environment's guidelines for large-scale municipal waste incinerators), and the Province of Alberta guidelines for large-scale incinerators in the oilfield (AEUB). Test details are not available.

10.2 Mediburner MBR 172, Mediburner Ltd., Finland.

See: www.mediburner.com/index.htm, also EmissionsMediburner-Unicef21.02.2.xls (spreadsheet).

This propane powered 72 kw unit is rated 12 kg/hr (6 safety boxes/hr). General cycle is to preheat < 30 min, incinerate < 40 min, pause approx 10 min, incinerate < 40 min, cool-off to 200 °C requiring from 30 - 60 min. A unit was tested by Oulu University Energy Laboratory (Finland) in three tests using medical wastes, batch loads from 1.9 to 3.2 kg and temperatures at high (780 – 1200 C) and low (530 – 1160 C) ranges. Concentrations of most pollutants (HCl, metals except Pb, Cr, Cd, Tl, and dioxin/furan) in stack gases fell below detection limits. Other emissions are shown in Table 6.

10.3 De Montfort, Applied Sciences Faculty, De Montfort University, Leicester, England

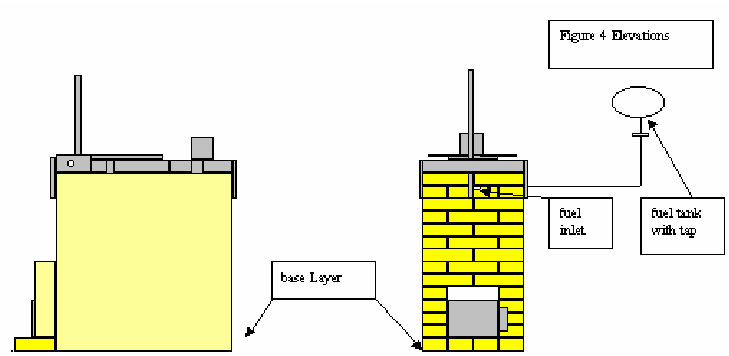
These relatively inexpensive high thermal capacity incinerators come in various models. The smaller models are:

- Mark 1: 12 kg/h of waste.
- Mark 2: Like Mark 1 with a larger secondary combustion chamber.
- Mark 7: Like Mark 1 specifically designed for use in emergency situations where it is essential to erect and bring into use quickly.
- Mark 8: Like Mark 7, but the body is brick-built, designed for areas where manufacturing facilities are very limited, and cost must be kept to a minimum. The Schematic below shows 8A with 5 m tall 0.12 – 0.15 m dia stack.

The larger models are:

- Mark 3: 50 kg/h (for hospitals up to 1000 beds)
- Mark 5: Like Mark 3, but modified to carry the weight of a much higher chimney

See: www.appsci.dmu.ac.uk/mwi/index.htm and other pages. Also, Pickens, DJ (undated) Emissions Test on a De Montfort Medical Waste Incinerator, Report. All photos below from Adama (2003).



Schematic from De Montfort website.

Photo from Burkina Faso

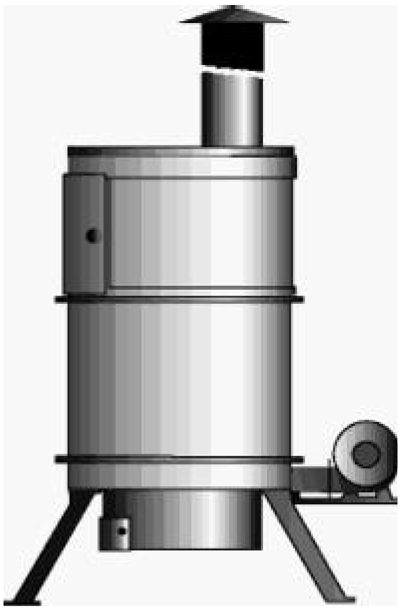
Photo from Kenya

Photo from Tanzania

Unknown

10.4 Vulcan and SICIM incinerators

Vulcan 160 (single chamber) incinerator can handle approximately 400 kg/day and achieve temperatures of 900 C. This can be locally built with an initial cost of approximately $6000 USD. Its dimensions are (l-w-h) 1 x 0.75 x 2.5 m and weighs ~800 kg. Operating cost is estimated to be $500 USD.



VULCAN incinerator

SICIN incinerator

11 Appendix C. Chapter 4, Operation, excerpts, from Operation and Maintenance of Hospital Waste Incinerators (EPA 1990)

4.4 Incinerator Operation, Control, and Monitoring

The key operating parameters for incinerators were presented in Section 4.2. This section provides a summary of the operating procedures, parameters which can be automatically controlled, and monitoring techniques for incineration systems. The operation, monitoring, and control of these four "typical" systems are discussed:

1. Batch feed controlled air;
2. Intermittent-duty controlled air;
3. Continuous-duty controlled air; and
4. Multiple chamber.

The operation, control, and monitoring of rotary kilns is not presented here because very few units are used to incinerate hospital waste and detailed information regarding their operation was not available.

4.4.1 Batch Feed Controlled-Air Incinerator

This type incinerator typically is a small unit, up to 500 lb/h, but more typically less than 200 lb/h capacity. The incinerator is operated in a "batch mode" over a 12- to 24-h period which entails a single charge at the beginning of the cycle, followed by combustion, ash burnout, cooldown, and ash removal. The operating cycle from startup to shutdown is discussed in the following sections. Parameters which can be automatically controlled and monitoring techniques also are discussed.

4.4.1.1 Incinerator Operating Procedures

4.4.1.1.1 Ash removal. Startup of the incinerator actually begins with removal of the ash generated from the previous operating cycle. The following are guidelines for good operating practice: 10

1. In general, allowing the incinerator to cool overnight is sufficient for the operator to remove the ash safely. This cooling can take as long as 8h.
2. The operator should open the ash cleanout door slowly both to minimize the possibility of damage to the door stop and seal gasket and to prevent ash from becoming entrained.
3. The operator should exercise caution since the refractory may still be hot and the ash may contain local hot spots, as well as sharp objects.
4. The ash and combustion chamber should not be sprayed with water to cool the chamber because rapid cooling from water sprays can adversely affect the refractory.
5. A flat blunt shovel, not sharp objects that can damage the refractory material, should be used for cleanup.
6. A void pushing ash into the underfire air ports.
7. Place the ash into a noncombustible heat resistant container, i.e., metal. Dampen the ash with water to cool and minimize fugitive emissions.
8. Once the ash has been removed and prior to closing the ash cleanout door, the operator should inspect the door seal gasket for frayed or worn sections. Worn seal gaskets should be replaced.
9. To prevent damage to the door seal gasket, the operator should close the ash cleanout door slowly and should not overtighten the door clamps. Overtightened door clamps may cause the seal gasket to permanently set and allow infiltration of outside air around the door face.

4.4.1.1.2 Waste charging. The operator may have the option of selecting which items are included in a particular charge. Waste properties which should be considered when the waste is segregated into charges include: (1) the heating value, (2) the moisture content, (3) the plastics content, and (4) the amount of pathological wastes. The heating value and moisture content of waste affects the performance of an incinerator. A charge of waste with a very high heating value may exceed the thermal capacity of the incinerator. The result is high combustion temperature, which can damage the refractory of the incinerator and can result in excessive emissions. Similarly, a charge of waste with a very high moisture content will not provide sufficient thermal input, and the charge will require the use of more auxiliary fuel than usual.

Plastic items are an example of materials with high heating values. Large quantities of plastic, which may contain polyvinyl chloride, should be distributed through many waste charges, not concentrated in one charge, if possible. When sorting loads of waste to be incinerated, the operator should try to create a mixture of low, medium, and high heating value wastes in each charge, if possible, to match the design heat release rate of the incinerator. In general, lighter bags and boxes will contain high levels of low density plastics which burn very fast and very hot. Heavier containers may contain liquids (e.g., blood, urine, dialysis fluids) and surgical and operating room materials which will burn slowly. As a general rule for segregating waste into charges, the operator may mix light bags and heavy bags to balance the heating value of each charge. If several different types of waste, (i.e., red-bag, garbage (cafeteria wastes), and trash) are being charged to the incinerator, charging the incinerator with some of each waste type is better than charging it with all of one waste type. Special care should be taken to avoid overcharging the incinerator (beyond its intended use) with anatomical wastes.

Prior to initiating charging, operation of the combustion air blowers and ignition and secondary burners should be checked. Follow the manufacturers' recommendations. The proper operation of the primary and secondary burners is best achieved by observing the burner flame pattern through the view ports in the incinerator wall or in the burner itself. Some burners are equipped with one observation point to view the main flame and another to view the pilot flame. The flame pattern will likely vary with the type of burner. However, the length of the flame should be such that the flame touches the waste but does not impinge directly on the refractory floor or wall. Obviously, the absence of a flame indicates a problem with the burner or the system that controls the burner.

Most burners are equipped with a flame safeguard system that includes a flame detector that effectively cuts off the fuel (gas or oil) supply to the burner if a flame is not detected. When the burner is first started, the burner blower starts and when it reaches full speed, a purge timer starts. When the purge timer times out, the flame safeguard energizes the pilot relay that opens the pilot fuel supply and ignitor. When the pilot lights, a flame detector (either an ultraviolet scanner [gas or oil] or flame rod circuit [gas only]) detects the flame and causes the main flame relay to activate the fuel supply to the main burner. The pilot then ignites the main burner. The flame detector continues to operate and shuts the burner down if the main burner fails. Additionally, if the air supply is lost both pilot and flame relays shut off the fuel supply. The pilot usually is ignited for no more than 15 seconds (interrupted pilot). If the main burner does not ignite during the period, the flame safeguard system shuts the entire system down.[18]

The incinerator is charged cold. Because these units generally are small, they are usually loaded manually. The waste is loaded into the ignition chamber, which is filled to the capacity recommended by the manufacturer. Typically, the manufacturer will recommend filling the incinerator completely, but not overstuffing the chamber. Overstuffing can result in blockage of the air port to the combustion chamber and in premature ignition of the waste and poor performance (i.e., excess emissions) during startup. Overstuffing also can result in blockage of the ignition burner port and damage to the burner. After charging is completed, the charge door seal gasket is visually checked for irregularities. The door is then slowly closed and locked. The charge door seal gasket should then be inspected for any gaps that would allow air infiltration into the primary chamber. Once operation is initiated, no further charges will be made until the next operating cycle is initiated, i.e., after cooldown and ash removal.

4.4.1.1.3 Waste ignition. Prior to ignition of the waste, the secondary combustion chamber is preheated to a predetermined temperature by igniting the secondary burner. A minimum secondary chamber temperature of 980°C (1800°F) is recommended prior to ignition of the waste. The manufacturer should be consulted regarding proper preheat procedures; improper preheat can result in refractory damage.

After the secondary chamber is preheated, the secondary combustion air blower is turned on to provide excess air for mixing with the combustion gases from the primary chamber.

The primary chamber combustion air blower is activated and the primary burner is ignited to initiate waste combustion. When the primary chamber reaches a preset temperature (i.e., the minimum operating temperature for the primary chamber, see Table 4-1) and the waste combustion is self-sustaining, the primary burner is shutdown.

The primary combustion air and secondary combustion air are adjusted 'to maintain the desired primary and secondary chamber temperatures. (Typically this adjustment is automatic and can encompass switching from high to low settings or complete modulation over an operating range.) During operation, the primary burner is reignited if the ignition chamber temperature falls below a preset temperature. Similarly, the secondary burner is reduced to its lowest firing level if the secondary chamber rises above a preset high temperature setting. Again, control of the burners, like the combustion air, is typically automated. A barometric damper on the stack is used to maintain draft. The incinerator chambers should both be maintained under negative draft.

4.4.1.1.4 Burndown. After the waste burns down and all volatiles have been released, the primary chamber combustion air level is increased to facilitate complete combustion of the fixed carbon remaining in the ash. The temperature in the primary chamber will continue to decrease indicating combustion is complete. During the burndown period, the primary burner is used to maintain the primary chamber temperature at the predetermined minimum level of the operating range. The length of time required for the burndown period depends on the incinerator design, waste characteristics, and degree of burnout desired. A typical burndown period is 2 to 4 h.[14] When combustion is complete, the primary and secondary burners are shutdown.

Shutdown of the secondary burner which initiates the cooldown period usually is automatically determined by a preset length of time into the cycle.[9,11] The combustion air blowers are left operating to cool the chambers prior to subsequent ash removal. The blowers are shutdown when the chambers are completely cooled or prior to opening the ash door for ash removal. Cooldown typically lasts 5 to 8 h.[14]

The final step in the cycle is examination of ash burnout quality. Inspection of the ash is one tool the operator has for evaluating incinerator performance. The operator should look for fine gray ash with the consistency of ash found in the fireplace at home or in the barbeque grill. Ash containing large pieces of unburned material (other than materials which are not combustible, such as cans) shows that incinerator performance is poor. It may be necessary to return these large pieces of material to the incinerator to be reburned because poor quality ash may be refused at landfills for disposal. Ash color also is an indicator of ash quality. White or gray ash indicates that a low percentage of carbon remains in the ash. Black ash indicates higher carbon percentages remaining. Although carbon remaining in the ash indicates that available fuel has not been used and combustion has not been complete, the fact that carbon remains in the ash is not in itself an environmental concern or an indicator that the ash is not sterile. Nonetheless, ash color can be used to assist the operator in evaluating burnout and incinerator performance.

4.4.1.1.5 Special considerations. If pathological waste is being burned, the ignition burner should be set to remain on until the waste is completely burned. Further, the volume of waste charged likely will need to be significantly reduced. The time required to burn an equivalent volume of Type 4 waste will be extended, since the waste contains high moisture and low volatile content. To destroy pathological waste efficiently, the waste must be directly exposed to the burner flame; consequently piling pathological waste in a deep pile (e.g., filling the entire chamber) will result in inefficient combustion. 15 If large volumes of pathological wastes are to be incinerated, an incinerator which is especially designed for pathological waste should be used.

4.4.1.2 Automatic Controls

Various levels of automatic controls are available for hospital incinerators, even for the smallest units sold. The smallest batch type units can be designed to use the same automatic control concepts and hardware for the key combustion control parameters (e.g., temperature and combustion air) as the larger continuous-duty incinerators.19 The use of control systems allows key combustion parameters to be adjusted automatically based on data (e.g. , temperature) from the incineration system. These automatic controls permit the combustion process to be more closely controlled. For batch feed systems, parameters that can be automatically controlled include:

1. Charging frequency;
2. Combustion air rate;
3. Primary and secondary burner operation;
4. Temperature; and
5. Combustion, burndown, and cooldown cycle times.

4.4.1.2.1 Charging frequency. The charging frequency can be automatically controlled by providing an interlock system on the charging door. The interlock will prevent the charging door from being opened after the primary burner is ignited and will prevent additional charges to the batch system until after burndown and cooldown have been completed. The operation of the interlock can be set up in one of two ways. The interlock can be activated by a timer so that the door cannot be opened until after a preset time has elapsed (e.g., 24 hours). Alternatively, operation of the interlock can be based on temperature; the interlock is set to deactivate only after the proper temperature in the cool down cycle is attained. The latter approach truly controls operation of the unit in a manner that assures the incinerator will run through the complete charge, combustion, burnout, and cooldown cycle.

4.4.1.2.2 Combustion air rate. Combustion air rate can be automatically controlled by on/off settings, low/high settings, and full modulation of the flow over an entire operating range. The control settings can be activated based upon the value of a monitored parameter (e.g., temperature) or by a specified time in a cycle. Some manufacturers are now using different types of more advanced combustion air controls that sense parameters such as gas flow, opacity, oxygen concentration, and loading cycles to assure that adequate combustion air is available in the secondary chamber.

4.4.1.2.3 Primary and secondary burner operation. Like the combustion air, the ignition and main combustion (secondary chamber) burners can be controlled over an entire operating range (i.e., modulated), at low/high levels, or in the on/off position. The settings can be based upon a monitored value (e.g., temperature) or as part of a timed sequence. The use of such settings in a control system is discussed in the following sections.

Table 4-3. Example Timed Control Cycle for Batch Mode Incinerator

Cycle	Controlling Parameter/Level	Resulting Automatic Control Action
1. Secondary combustion chamber preheat	Manual start	Secondary burner--High fire
2. Ignition	Combustion chamber temperature reaches 1100°F	Secondary combustion air--high level
		Primary combustion air--high level
		Primary burner on
3. Combustion	Primary chamber temperature reaches 1000°F	Primary burner off
	Secondary temperature reaches high set point, 2000°F	Secondary burner switches to low fire
	Secondary temperature reaches low set point, 1800°F	Secondary burner switches back to high fire
	(Burner will cycle as high/low set-points are reached)	
4. Burndown	5 hours from ignition	Primary air switched to high
	High primary temperature override	Primary air switched back to low
	1 hour after override activated	Primary air switched to high level
5. Cooldown	8 hours from ignition	Secondary burner shuts off
	16 hours from ignition; cycle completed	Combustion air blowers shut off

4.4.1.2.4 Temperature. Both the primary ignition and secondary combustion chamber temperatures can be automatically controlled. At least two levels of control are available. The first control approach is designed to control temperature in each chamber by modulating the available combustion air to each chamber. In this type system, the temperature in each chamber is monitored, and the combustion air to each chamber is separately controlled based on feedback from the thermocouples. The combustion air is modulated continuously over a wide range in order to maintain the set point temperatures. Auxiliary burners are used as necessary to maintain minimum temperatures. Since instantaneous peaks in the combustion gases generated in the primary chamber can occur, some manufacturers recommend operating the secondary burner at all times (in a low fire position if heat is not required) to assure complete combustion of primary chamber gases.[4]

This type control system effectively controls the waste combustion rate in the primary chamber by controlling the combustion air. Controlling the combustion rate in the primary chamber subsequently limits the combustion rate in the secondary chamber. Controlling the secondary chamber combustion air controls that chamber's temperature by increasing or decreasing the excess-air level. The firing rate of the main combustion burner (secondary chamber) may be modulated upward or downward if low and high temperature set points are reached in the secondary chamber. Similarly, the ignition burner can be activated automatically if the primary chamber temperature falls below the minimum set point. This type system provides a true control of the key parameter, combustion temperature, by modulating the combustion air.

One manufacturer controls the combustion rate in the primary chamber and the temperature in the secondary chamber by monitoring the oxygen concentrations in each combustion chamber and using these data to control/adjust the combustion air levels.[20]

Review of manufacturers' information indicate that a second approach to automatically controlling the combustion process is used for batch type units.9,11 In this approach, a series of timers are used to establish a timed sequence of events and the key process equipment (i.e., burners and combustion air) have high/low or on/off settings. The switching of the burners and combustion air from one setting to another is controlled by the timed sequence. Overrides for the timed sequence are typically provided to assure that minimum or maximum set point temperatures are not exceeded.

This type control system does not offer the same level of combustion control as the modulated system previously described. Instead of continuously modulating to achieve a specific set point (i.e., temperature), this type system utilizes on/off or low/high settings to maintain control between two set points.

4.4.1.2.5 Combustion, burndown, and cooldown cycle times. An automatic control sequence operating on a timer cycle typically is used to initiate and control the length of burndown and cooldown cycles. An example timed control cycle for a batch operated incinerator is presented in Table 4-3.

4.4.1.3 Monitoring Operations

The monitoring of key operating parameters provides several benefits. First, monitoring provides the operator with information needed to make decisions on necessary combustion control adjustments. For example, continuous monitoring of the temperature and carbon monoxide level of the secondary combustion chamber effluent gas stream allows the operator to determine whether optimum combustion conditions are being maintained. Indications of an abnormally high CO level and low temperature can immediately be used to adjust the secondary burner rate to raise the combustion chamber temperature. Second, properly maintained monitoring records can provide useful information for identifying operating trends and potential maintenance problems. This historical information can be used to make decisions with respect to modifying standard operating procedures or control set points. For example, careful visual inspection of ash quality each day complemented by comments in a daily operator's log book can be used to track ash burnout patterns. If a gradual trend towards poor ash burnout becomes evident, identification of possible reasons and corrective actions can be initiated. Finally, monitoring generally is needed to satisfy regulatory requirements.

Monitoring can be divided into three broad categories:

1. Continuous monitoring - involves continuous instrumental measurement with continuous data recording; e.g., use of a temperature sensor with a strip chart recorder.
2. Continuous measurement - involves continuous instrumental measurement but requires the operator to monitor the data output manually; e.g., use of a temperature sensor with a digital meter display.
3. Manual monitoring - involves inspection by the operator on a noncontinuous basis, e.g., visual stack gas opacity readings.

All of these techniques can be used to monitor the operation of batch type incinerators. Continuous monitoring of operating parameters will, in most cases, provide more information than manual monitoring. For example, continuous opacity monitoring of stack gas opacity will provide opacity data for the entire operating period and will provide a permanent record of changes in opacity over the operating cycle and trends over time. On the other hand, visual inspection of the stack gas opacity will provide limited data, and a record will be available only if the observer records the result.

The following operating parameters can be monitored:

1. Charge rate;
2. Combustion gas temperature;
3. Condition of the waste bed and burner flame;
4. Combustion gas oxygen level;
5. Combustion gas carbon monoxide level;
6. Combustion gas opacity;
7. Auxiliary fuel usage; and
8. Ash quality.

The techniques for monitoring each of these parameters are briefly described in the following paragraphs. Note that this section is not intended to recommend specific monitoring requirements, but is intended to present the key parameters which can be monitored and provide a brief description of how the parameters can be monitored and what useful information monitoring can provide. Chapter 6 further discusses actual instrumental monitoring methods.

4.4.1.3.1 Charge rate. The weight of each charge can be recorded in a log book. This procedure will help to indicate whether the rated capacity of the incinerator is being exceeded. Note that incinerators are designed for a specific thermal input. Since the heat value (Btu/lb) of wastes will vary, the weight of a charge is not a true indicator of whether the rated capacity is being exceeded. Variations in heating value in the waste will need to be considered in determining charge size.

Nonetheless, monitoring the weight of the charge will provide historical data which can be used to make systematic modifications to operating procedures, i.e., reduction of the charge rate by 20 percent to evaluate the effect on resolving poor burnout problems. Monitoring this parameter will require a scale or weigh bin which can be used to weigh individual waste bags or transport carts.

4.4.1.3.2 Combustion gas temperature. The combustion gas temperatures (primary and secondary) are critical operating parameters. These parameters typically are monitored continuously using thermocouples. Permanent strip chart (or data logger records) may be kept; for small units only meters without permanent recordkeeping typically are provided.

4.4.1.3.3 Condition of waste bed and burner flame. If viewports are provided in each chamber, the operator can view the flame pattern and the waste bed. Visual observation of the combustion process provides useful information on the burner operation (i.e., potential problems such as flame impingement on the refractory, or smoking of the secondary burner flame can be identified) and on the combustion process in general (i.e., quantity and condition of remaining waste charge can be identified).

Viewports should be sealed glass covered by blastgates. "Inspection doors" which open the chamber to atmosphere should not be used for viewing the combustion process because these pose safety problems and affect the combustion air control.

4.4.1.3.4 Combustion gas oxygen level. The combustion gas oxygen concentration is a direct measure of the excess-air level. Although this measurement is not essential, it provides real-time information about changing conditions in the combustion chamber. Typically, the oxygen level of the combustion gas exiting the secondary chamber is used to assure that excess air is always available for complete combustion. A continuous oxygen monitoring system typically is used (see Chapter 6). However, a portable instrumental measurement system also can be used occasionally for monitoring oxygen levels to confirm proper operation or to provide information necessary for adjusting combustion air dampers.

4.4.1.3.5 Combustion gas carbon monoxide level. Carbon monoxide is a product of incomplete combustion; excessive levels indicate that a poor combustion condition exists. The CO concentration of the combustion chamber effluent can be monitored continuously to alert the operator to poor combustion conditions. An instrumental CO monitoring system generally is used for this procedure (see Chapter 6). Alternatively, a portable instrumental measurement system can be used to make occasional measurements of CO to monitor performance. As with the oxygen measurements, this approach often is used to check performance in conjunction with maintenance or adjustment of combustion control level settings.

4.4.1.3.6 Combustion gas opacity. Combustion gas opacity provides an indirect measurement of particulate matter concentration in the stack gas; hence opacity is an indicator of incinerator performance. As particulate concentration increases, so does the opacity. Continuous emission monitoring systems (CEMS) for measuring opacity (referred to as "transmissometers") are available (see Chapter 6). An alternative, and simpler monitoring technique, is visual observation of the stack emissions. The opacity of the stack gas can be determined accurately by a trained observer. Even an untrained observer can detect gross changes in stack gas opacity and can use visual observations to note combustion problems.

4.4.1.3.7 Fuel usage. Monitoring fuel usage provides historical data for identifying maintenance problems and for identifying the need for adjustments to control system settings to increase efficiency. Fuel usage can be monitored with a simple metering system. Fuel usage can than be determined by logging meter readings or continuously recording the metering system's output.

4.4.1.3.8 Ash quality. Ash quality is one indication of combustion performance. Visual inspection is the simplest means of determining ash quality and incinerator performance. For example, large pieces of uncombusted materials (e.g., paper) indicate very poor ash quality. The operator should inspect the ash visually and record comments on ash quality in a log book routinely.

For a more technical determination of ash quality, a chemical analysis of a sample of the ash can be conducted. The amount of combustible materials remaining in the ash can be determined by a laboratory test which subjects a sample of the ash to a combustion atmosphere and then determines the weight loss. This procedure measures the ash's "burnout" quality. A 100 percent "burnout" means no volatile or combustible materials remain in the ash; some incinerators are capable of 90 percent burnout.[21] Occasional checks of ash burnout are useful for monitoring performance of the incinerator.

4.4.2 Intermittent-Duty , Controlled-Air Incinerators

Intermittent-duty, controlled-air incinerators typically are used for "shift" type operation. The incinerator must be routinely shutdown for ash removal. Hence, there is a distinct operating cycle.

The main feature which distinguishes this type incinerator from the batch incinerator is the charging procedures which are used. The charging system is designed to accommodate multiple charges safely throughout the operating cycle rather than rely on a single batch charge at the beginning of the operating cycle. Either manual or automated charging systems can be used.

4.4.2.1 Operation

4.4.2.1.1 Ash removal: The residual ash from the previous operating cycle must be removed before a cycle can be initiated. Ash removal procedures are essentially the same as those described in Section 4.3 for batch mode incinerators.

4.4.2.1.2 Startup. Before the operator initiates startup, proper operation of the primary and secondary burners and combustion air blowers should be checked according to manufacturer's instructions. The following steps are conducted during startup:

1. The primary and secondary burner(s) are ignited, and preheat of the combustion chambers is initiated. The manufacturer should be consulted regarding proper preheat procedures, since improper preheat can damage the refractory.
2. The secondary chamber must reach a predetermined temperature (e.g., 1800°F) before the incinerator is ready for charging; and
3. After the predetermined secondary chamber temperature is attained, the primary and secondary combustion air blowers are activated. The incinerator is ready to be charged.

4.4.2.1.3 Waste charging. Stable combustion can be maintained most readily with a constant thermal input to the incinerator. Feeding too much waste in a charge causes the incinerator to overload. These overloads can result in poor burndown (because of waste pile buildup on the hearth) or can cause excessive emissions because the rapid generation of volatiles overloads the capacity of the secondary chamber. Feeding too little waste results in inadequate thermal input and consequent excessive auxiliary fuel use.10 A charge frequency and quantity recommended by two manufacturers is 15 to 25 percent of the rated capacity (lb/h) at 10 to 15 minute intervals.l0,11 Another rule of thumb is to recharge the incinerator after the previous charge has been reduced by 50 to 75 percent in volume, determined by observation of the waste through the view ports or operating experience.[11] Charging volume and frequency will vary with waste composition, and the operator must use some judgment to determine appropriate rates. The temperature profile of a combustion chamber is a picture of how the temperature in the chamber fluctuates during the course of the incineration process. The variations in temperature are shown on the strip or circular chart recorder that records the temperatures measured by the thermocouples in the combustion chambers. The temperature fluctuations are affected by the frequency of waste charging and the size of the charge. Insufficient or infrequent charging may cause the temperature to become too low and necessitates the use of auxiliary fuel to help maintain the desired set point temperature. Charging too much waste may cause a rapid increase in secondary combustion chamber temperature if the waste has a high volatile content. On the other hand, if the waste has a low Btu content or contains a lot of moisture, overcharging may have the effect of first decreasing the primary combustion chamber temperature (while the moisture is being volatilized) before a temperature increase is noted. Charging on a regular basis with the same volume of waste in each charge helps to "flatten" the temperature variation and allow proper combustion while preventing refractory damage and excessive auxiliary fuel consumption. Monitoring the temperature profile of the combustion chambers will assist in determining the proper charging rates.

After the last charge of the day is completed, the incinerator is set to initiate the burndown cycle. The limiting factor on how long the charging period can be sustained without initiating the burndown cycle is the degree of ash buildup on the hearth. Typically the charging period is limited to 12 to 14 hours.[14]

4.4.2.1.4 Burndown. The burndown cycle is essentially the same as described for batch incinerators and is initiated after the last charge of the day is made. For intermittent-duty incinerators the burndown sequence can be initiated manually or may be initiated automatically. One manufacturer's control system is designed to include a control timer which is activated by the charging door.[11] Whenever the charging door is opened and then closed, the burndown timing cycle is initiated by resetting the burndown timer to a preset time period, e.g., 5 hours (the actual length of the burndown time is determined by experience with waste stream).

4.4.2.1.5 Cooldown. The cooldown period is the same as for batch incinerators.

4.4.2.2 Automatic Controls

The parameters which can be controlled automatically for intermittent-duty controlled-air incinerators are essentially the same as those already discussed for the batch-operated incinerators. The automatic control techniques used also are essentially the same. Either timed sequences with high/low burner and air settings or control systems which have fully modulated burner and air controls that are continually adjusted based on control feedback (e.g., temperature) can be used. For intermittent-duty units, the charging rate can be controlled automatically if an automatic mechanical charging system is provided with the unit. Automatic control for a ram feed charger consists of a timing sequence which will initiate the charging sequence at regularly timed intervals. The size of the charge is controlled by the volume of the feed hopper. An override on the automatic feeder can be provided so that the control system will not allow a charge to be fed at the regular interval if certain conditions are not met. For example, if the primary chamber temperature exceeds a high level set point, the incinerator is not yet ready for another "fuel" charge and the charging cycle will not initiate.

4.4.2.3 Monitoring

The operating parameters that can be monitored for intermittent-duty incinerators are the same as those parameters discussed in Section

4.4.1.3 for batch incinerators. The same monitoring techniques generally apply. However, continuous monitoring and recording of the ignition and combustion chamber temperatures have added importance for intermittent-duty incinerators. The trends in these measured values are useful to the operator in determining the appropriate charging frequency and in adjusting the charging frequency as waste characteristics change. Similarly, the use of appropriate viewports has added significance in making decisions on charging frequency based upon appearance of the waste bed.