

# Small-scale medical waste incinerators – experiences and trials in South Africa

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## Abstract

Formal waste management services are not accessible for the majority of primary healthcare clinics on the African continent, and affordable and practicable technology solutions are required in the developing country context. In response, a protocol was established for the first quantitative and qualitative evaluation of relatively low cost small-scale incinerators for use at rural primary healthcare clinics. The protocol comprised the first phase of four, which defined the comprehensive trials of three incineration units. The trials showed that all of the units could be used to render medical waste non-infectious, and to destroy syringes or render needles unsuitable for reuse. Emission loads from the incinerators are higher than large-scale commercial incinerators, but a panel of experts considered the incinerators to be more acceptable compared to the other waste treatment and disposal options available in under-serviced rural areas. However, the incinerators must be used within a safe waste management programme that provides the necessary resources in the form of collection containers, maintenance support, acceptable energy sources, and understandable operational instructions for the incinerators, whilst minimising the exposure risks to emissions through the correct placement of the units in relation to the clinic and the surrounding communities. On-going training and awareness building are essential in order to ensure that the incinerators are correctly used as a sustainable waste treatment option.

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## 1. Introduction

Change and change processes are foremost in developing countries. In this respect South Africa has been one of the focal points in the world because of the dramatic process of change to a transparent and true democracy. Whilst the country is progressing through this continuum of change, the healthcare system is also transforming itself into a district-based system with particular emphasis on a primary healthcare system (South African Ministry of Health, 1996). Some 40% of all South Africans live in poverty (Brent et al., 2002), and 75% of these live in rural areas where they were previously deprived of access to the health

services (Statistics South Africa, 2004). Limited financial resources are available to fund the major changes in all facets of the South African society, and from a sustainable health perspective the priorities are based on providing affordable, accessible, safe healthcare to all of the population. Although South Africa is one of the strongest economies on the African continent, these processes of change and the pressure of expectations pose challenges to the sustainability of the service offerings in the national health care system.

Medical waste management is a fundamental strategic function in safe and responsible healthcare and is actively addressed (WHO, 2004) by various bodies such as WHO, UNICEF, USAID, national governments and specifically through various organisations and collaborations such as WHO Technet consultative forum, WHO Safe Injection Global Network (SIGN), and the Global Alliance for

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Vaccine and Injections (GAVI). In 1998 the WHO Technet forum decided to actively investigate and seek answers to support the objectives of promoting improved medical waste management (WHO, 1998) as part of safe injection practices (Battersby et al., 1999). In South Africa, the poor level of medical waste management had already been identified by the national government (South African Ministry of Health, 1996). A process of transformation of waste management had been initiated separately through a National Waste Management Strategy (South African Department of Environmental Affairs and Tourism, 1999), and the Ministry of Health had issued a request for a more affordable solution for the handling of medical waste at rural primary healthcare clinics (South African Ministry of Health, 1996). In this respect medical waste incineration has been identified as a potential cost-effective method for healthcare waste treatment (Lee et al., 2004), especially in developing countries (Diaz et al., 2005).

Regulations governing the emissions from large commercial Medical Waste Incinerators (MWIs) are stipulated in South Africa (Department of Environmental Affairs and Tourism, 2004), which are currently under revision. A less stringent set of performance criteria has been under consideration by the Department of Environmental Affairs and Tourism (DEAT) for the operation of MWIs at primary healthcare clinics, on the basis that although the emission loads are typically higher, the frequency of use of the incinerators is lower and results in a lesser overall emission load into the atmosphere, and the population surrounding the incinerators is less dense, which reduces the consequent exposure of the population to the emissions.

In this context the South African Collaborative Centre for Cold Chain Management established a protocol for the first quantitative and qualitative evaluation of relatively low cost small-scale incinerators for use at rural primary healthcare clinics (SACCCCM, 1999). The practical experience of the programme was shared with members of the WHO Technet and UNICEF Kazakhstan, where a similar evaluation had taken place (Brent and Rogers, 1999a).

### 1.1. Background to the South African evaluation trials

Many problematic waste management issues have been identified for healthcare clinics in South African rural areas (Phillips et al., 1999) and under-serviced areas in other parts of the world (Da Silva et al., 2005). The trials therefore had to take into account these variables and practices and aimed to provide a more scientific method of determining the usability of small-scale medical waste incinerators in rural, under-serviced clinic settings. Financial resources restricted comprehensive trials, which could evaluate incinerators, evaluate total clinic waste management needs and practices, redevelop the incinerators and set total guidelines for medical waste management at rural primary healthcare clinics. The trials therefore concentrated on the initiation of a baseline assessment of the process of medical waste management through:

- Quantitative analyses of the performance of different incinerators in controlled laboratory conditions with identical waste loads (Brent and Rogers, 1999b,c).
- Qualitative (Phillips et al., 1999) and quantitative analyses (Brent et al., 1999) of the performance of the incinerators during their use at actual clinics, with guidelines on waste loading procedures, but with no changes to current waste management practices (such as waste streaming, contents of loads, etc.). Involvement of all of the stakeholders, including the regulatory authorities, health workers and the communities, was ensured during these analyses. It was also attempted to correlate the field results with the performance analyses in the laboratory.
- Seeking acceptance of the regulatory stakeholders to evaluate the performance of the incinerators for each individual clinic site in the trial. This process also indicates to all stakeholders the role that these kinds of incinerators have to play in the management of medical waste in rural primary healthcare clinics.

The final and only objective of the trials was to present the South African Department of Health with specification guidelines (Rogers and Brent, 1999) and information upon which a tender specification could be formulated by the National Department for the procurement of small-scale medical waste incinerators for use at rural primary healthcare clinics.

## 2. Method

The trials were carried out in four phases so as to provide for reporting and to allow the incorporation of feedback and input from stakeholders in the decisions made during the trials.

### 2.1. Phase 1: Preparation of a protocol for the trials

Responsible parties and stakeholders were identified during a scoping study, as well as the key requirements for participation in the trials. A protocol was prepared for the trials that addressed all of the regulatory and technical issues of the stakeholders. Incinerator manufacturers were specifically invited to take part in the trials and four models were submitted for testing, applying three sources of energy, i.e., wood (2), gas, and electricity. A typical waste composition was identified based on field experience and knowledge of the clinic operations (Phillips et al., 1999). Uninfected waste was made up for the remainder of the trials. The composition of the waste is shown in Table 1 (Brent and Rogers, 1999b).

### 2.2. Phase 2: Laboratory tests on the small-scale incinerators

The objective of the laboratory tests was to establish whether the incinerators were considered safe enough to submit to field trials at remote primary healthcare clinics

Table 1  
Composition of the made up uninfected medical waste for the trials  
(Phillips et al., 1999)

Content	Percentage of total weight (%)
Unused needles with syringes	39.5
Bandages	10.5
Cotton wool	1.3
Wrappings	7.2
Used glass vials and bottles	12.7

The sharp wastes (needles, syringes and glass) were collected in a 5 l ( $0.3 \text{ m} \times 0.165 \times 0.125 \text{ m}^3$  external dimensions) cardboard UNICEF acceptable safety box (27.8%wt). The other waste (softs) was collected in 5 l polyethylene plastic bags (1% wt). Products of conception and body parts were excluded as these emergency procedures occur infrequently at primary healthcare facilities in South Africa.

where the clinic staff were to operate the incinerators. Laboratory tests on the emissions and waste destruction performances were carried out in an incineration test facility at the Council for Scientific and industrial Research (CSIR) in South Africa (see Figs. 1 and 2). The operating procedures supplied by the manufacturers of the test units were insufficient for the laboratory tests, e.g., the mass of waste to be loaded, and it was necessary to make additions to the procedures in order to achieve acceptable results in terms of the maximum capacity of each unit (Brent and Rogers, 1999b). Quantitative measurements were made on the emissions identified in the South African incineration guidelines (South African Department of Environmental Affairs and Tourism, 2004). On-line measurements were taken for combustion zone temperatures and combustion efficiency, i.e., carbon



Fig. 1. The loading of the made up waste into the electrical unit.

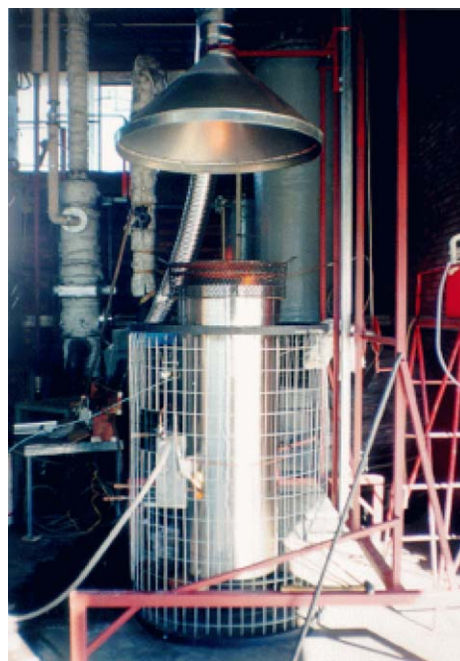


Fig. 2. Laboratory tests on the gas-fired unit.

monoxide and dioxide, and oxygen, as well as sulphur dioxide according to standard US EPA methods (Brent and Rogers, 1999b; US EPA, 2005). The destruction efficiency was determined by the mass reduction of the waste. Integrated samples were collected for total particulate emissions and gaseous chloride, based on stipulated standards (US EPA, 2005; ISO, 2003) and previous experiences on testing coal-fired stoves (Rogers, 1995). The particulate matter was analysed for the hazardous metallic elements arsenic, lead, cadmium, chrome, nickel, antimony, barium, silver, cobalt, copper, tin, vanadium and thallium (Brent and Rogers, 1999b; US EPA, 2005). Complex organic substances such as dioxin were not measured; due to technical and operations characteristics of the small-scale incinerators, many of these substances would form in the plumes, which makes physical measurements altogether problematic (Brent and Rogers, 2002). Qualitative assessments were made on user safety and usability for typical staff (nurses, gardeners and security guards) at primary healthcare clinics. A nurse from the National Department of Health, an emissions scientist and a combustion engineer from the CSIR were used for the assessments.

### 2.3. Phase 3: Field tests at remote rural primary healthcare clinics

Field trials were carried out over 3 months to obtain a qualitative assessment of the performances of the incinerators under actual clinic conditions (Phillips et al., 1999). Three of the nine South African Provinces (Kwa-Zulu Natal, Northern Cape, and Gauteng) took part in the trial (see Fig. 3). Each provided at least one clinic, which received an



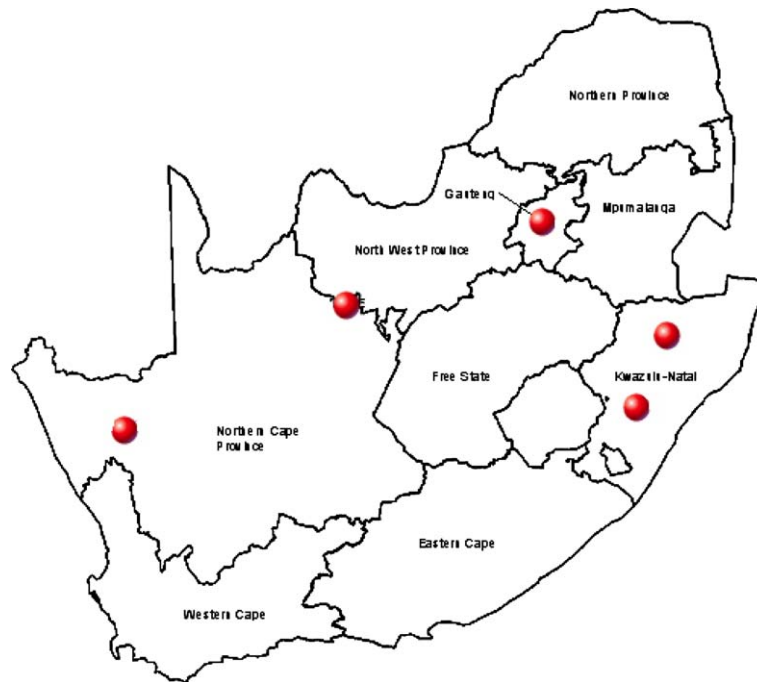


Fig. 3. Map of selected in primary healthcare clinics in South Africa.

incinerator along with training by the incinerator manufacturer. The criteria for selecting the clinics in Kwa-Zulu Natal (population 9,426,017 and area 92,100 km<sup>2</sup>), and Northern Cape (population 822,727 and area 361,830 km<sup>2</sup>) (Statistics South Africa, 2004) were based on the lack of a practicable waste transportation services to the district hospitals, which have large-scale incinerators. In the case of Gauteng (population 8,837,178 and area 17,010 km<sup>2</sup>) (Statistics South Africa, 2004), which is smaller and has a higher developed infrastructure, the criteria

were based on the services and the rural population served. User acceptability was assessed with questionnaires supplied to the coordinators of the trials in the Provinces (Phillips et al., 1999). The fields surveyed were perceptions of safety, destruction capability, usability for the available staff, and community acceptability. Members of the project steering committee were also invited to visit the clinics and complete the questionnaires. User safety and operating procedures were assessed by a site inspection. Fig. 4 illustrates the typical operation of the wood-fired incineration unit.

Quantitative measurements were also performed on two incineration units (wood- and gas-fired) at the clinic in Gauteng (Brent et al., 1999) with a mobile laboratory (see Fig. 5). On-line measurements were again taken for combustion zone temperatures and combustion efficiency, and the destruction efficiency was measured in terms of mass reduction of the waste. Particulate matter and other gaseous substances were not measured.

#### 2.4. Phase 4: Selection of technical performance specifications for the Department of Health

A set of performance specifications was prepared, based on the findings of the laboratory and field tests. None of the incinerators complied with the South African emission guidelines for conventional large-scale incinerators (South African Department of Environmental Affairs and Tourism, 2004). Recommendations were made for exemptions for small-scale units at remote rural primary healthcare clinics based on the composition and quantities of waste, and lack of other practicable options.



Fig. 4. The wood-fired unit at the clinic in Gauteng.



Fig. 5. Testing of the gas-fired unit at the clinic in Gauteng.

### 3. Results

#### 3.1. Phase 2: Laboratory tests on the small-scale incinerators

The main findings from the laboratory trials can be summarised as follows:

- Three of the four units were found to be able to accommodate the waste containers used for the trial. One wood-fired unit was too small (0.3 m high) to accommo-

date the bed of wood coals as well as the sharps box and for this reason gave off excessive smoke and was not able to burn the plastic syringes, which melted and flowed from the base. For this reason this unit was not considered suitable for the field trials.

- The three units could be used to render medical waste non-infectious, and to destroy syringes or render needles unsuitable for reuse.
- The emissions from the units are summarised in Table 2. The largest deviations from the South African guidelines for large-scale incinerators are the gas combustion efficiencies that indicate the extent to which hazardous organic substances are emitted. These are estimated to be up to 200 times more than the guidelines. Chromium also exceeded the guidelines within a factor of two, the source of which is expected to be the stainless steel needles. Soot was also found to be approximately 50% by weight and supports the finding of the relatively low combustion efficiency. The other deviations (see Table 2) are of minor importance. Nevertheless, the emission loads from small-scale incinerators are expected to be lower than those from a wood fire, but higher than a conventional fire-brick-lined multi-chambered incinerator (Brent et al., 1997; Diaz et al., 2005). For some of the units large pieces of cardboard rained down from the exhaust and this could constitute a fire hazard if the unit is not operated in an area free from combustibles. The release point of the smoke is above the inhalation zone of the operator.
- The poorest combustion efficiency was found from the wood-fired units, and the best combustion efficiency was found with the gas-fired and the electrical fan driven units. The combustion efficiency, together with other parameters such as particulate and metals concentra-

Table 2

Results of the laboratory tests on the four incinerators (Brent and Rogers, 1999b)

Measured parameter <sup>a</sup>	Units	Tested incinerators				SA Process Guide
		Molope gas	Molope auto (wood)	C & S (electrical)	PaHuOy (wood)	
Stack height	m	1.8	1.8	1.9	0.3	3 m above nearest building
Gas velocity	m/s	±0.8	±0.5	1.1	±0.5	10
Residence time <sup>b</sup>	s	0.4	0.7	0.6	0.4	2
Minimum combustion zone temperature	°C	800–900	400–650	600–800	500–700	>850
CO <sub>2</sub> at the stack tip	% vol	2.64	3.75	4.9	3.25	8.0
Gas combustion efficiency	%	99.91–99.70	98.8–98.4	99.69–99.03	98.9	99.99
Particulate emissions	mg/Nm <sup>3</sup>	102	197	130	338	180
Particulate fall-out	mg/Nm <sup>3</sup>	±42	±105	n.d.	n.d.	–
Soot in particulates	%	42.2	58.1	48.7	84.8	–
Ash residual (waste)	%	14.8	12.9	15.6	21.7	–
Cl as HCl	mg/Nm <sup>3</sup>	46	13	25	35 & 542	<30
F as HF	mg/Nm <sup>3</sup>	<6	<1	<2	<1	<30
Chromium (Cr) <sup>c</sup>	mg/Nm <sup>3</sup>	<0.1	0.7	0.7	<0.1	0.5
Manganese (Mn) <sup>c</sup>	mg/Nm <sup>3</sup>	<0.1	0.3	0.3	<0.1	0.5
Nickel (Ni) <sup>c</sup>	mg/Nm <sup>3</sup>	<0.1	0.3	<0.1	<0.1	0.5
Vanadium (V) <sup>c</sup>	mg/Nm <sup>3</sup>	<0.1	<0.1	0.4	<0.1	0.5

<sup>a</sup> Parameters are corrected to 8% CO<sub>2</sub> where applicable for comparison purposes with the SA guidelines.

<sup>b</sup> Residence time is taken to be the total combustion time, and the maximum achievable.

<sup>c</sup> All other metallic elements were below the detection limit of the analytical procedure.

tion, is an indication of the possible risk of organic compound formation (such as dioxins and furans) after the release of gases from the incineration chamber (Brent and Rogers, 2002).

### 3.2. Phase 3: Field tests at remote rural primary healthcare clinics

The assessment of the destruction capability of the incinerators in the field showed that the waste is destroyed adequately and sharps are rendered unusable similarly to the laboratory trials. The operational characteristics for the wood-fired unit, however, differed significantly when comparing the field and laboratory results (see Fig. 4). This is attributable to overloading due to incorrect training of the clinic staff, low quality wood fuel, and the supply of incorrect waste collection containers to the clinic.

Specific findings were made in terms of safety issues relating to the incineration units (Phillips et al., 1999):

- One of the main concerns was the operator and community safety due to the low stack height (approximately 2 m above the ground). In practice the operators were typically positioned upwind and the exposure to smoke was for a short period during initial light up in the case of the wood and electrical fan units. Provided that the infectious waste is not used for ignition, it was judged that the risk is less than that of lighting a fire. An initial concern was that there was the risk of direct inhalation at distances of 20–50 m by clinic staff and patients. Apart from the rectifications that were required for the wood-fired unit, other observations during the site inspections did not highlight this risk in practice and it was not reported on the questionnaires received from the clinics.
- There was a general awareness of the importance of waste disposal, segregation, storage and the use of safety equipment. However, the clinics had a low awareness of the hazardous nature of incinerator ash. It is classified as hazardous material (South African Department of

Water Affairs and Forestry, 1998) due to the presence of needles and sharps, the risk of some non-destroyed pathogens and the presence of hazardous substances. It was found that prior to the training of personnel for the trials, precautions for the collection and disposal of ash had not been taken and ash was placed in shallow unprotected pits.

- Spillage of material during the loading and unloading of the incinerators was identified as a hazard for which most staff members were unprepared.

The operators of the incinerators are typically illiterate or semiliterate, for which detailed training manuals are of little use. Furthermore, for some of the clinics, more than one operator used the incinerator, with one operator training another. Operational problems were subsequently attributed to this training. Formal waste management training is therefore required for specific categories of staff and general awareness training is required for all staff at the hospital.

Some deformation of metal was observed on the two highest temperature units and this affected the ease with which the units could be operated. Some local arrangements for maintenance would be required for on-going operations.

A quantitative comparison of the performance in the field with the laboratory trials was made (Brent and Rogers, 1999b; Brent et al., 1999). The waste composition at the clinics was examined visually and found to be similar to that used in the laboratory trials. The effects of changes in waste composition were therefore not expected to be significant. The effects of changes in the wood fuel were tested at the clinic in Gauteng. Measurements of temperature and gas combustion efficiency showed that the local wood burnt out faster and produced on average more emissions. The combustion conditions with wood are consequently more difficult to control due to the variable quality in the field. The effect of overloading of the incinerators was tested when the operator loaded the gas fired unit with a 40-l bag of soft wastes in place of the 5 l tested in the laboratory. The temperature and emission performance with

Table 3  
Field tests of the wood- and gas-fired incinerators (Brent et al., 1999)

Measured parameter	Units	Molope gas	Molope auto (wood)	Comments
Minimum combustion zone temperature	°C	800–1100	400–1000	High temperatures are attributed to the composition and energy content of the waste material, e.g. plastic instead of cardboard used in Molope Gas unit, and a larger fuel bed in the Molope Auto unit.
CO <sub>2</sub> at the stack tip (average for the waste burn)	% vol	5.35	5.05	For the SA guidelines, parameter values are normalized to 8% CO <sub>2</sub> and normal temperature and pressure for reporting purposes.
Gas combustion efficiency (average for the waste)	%	98.37	97.14	Calculated value may be low due unsatisfactory mixing of the gases at the measurement locations.
Gas combustion efficiency (average for the fuel)	%	99.92	98.55	An indication of the amount and type of fuel used.
Ash residual (waste)	%	21.9	10.4	This is a measure of the destruction efficiency of the incinerators. Typical commercial units operate at 85–90% mass reduction.

Table 4  
Proposed technical specifications for the incinerators in South Africa (Rogers and Brent, 1999)

Parameter	Units	Small scale medical waste incinerator	Conventional licensed large scale medical waste incinerator
Hours of operation per week	–	2	40
Amount of waste destroyed per week	kg	Maximum of 10	4000–40000
Size of waste container per loading	–	5 l sharps box <sup>a</sup> , or 5 l softs bag	5–90 l safety boxes
Stack height (m) on flat ground and at least 15 m from adjacent buildings	m	Minimum of 1.8	9 or 3–6 m higher than the adjacent roof <sup>b</sup>
Particulate emissions	mg/Nm <sup>3</sup>	360	180
Emissions of metals <sup>c</sup>	mg/Nm <sup>3</sup>	1	0.5 and 0.05
Emission of Cl	mg/Nm <sup>3</sup>	<60	<30
Gas combustion efficiency	%	99.0	99.99
Minimum operating temperature in combustion zone	°C	650	Not specified
Minimum wall temperature in combustion zone	°C	Not specified	850

<sup>a</sup> The Department of Health approved safety box, which has been demonstrated as meeting these performance requirements is the UNICEF approved 5 l cardboard box.

<sup>b</sup> DEAT Guideline for a pitch roof is 3 m and for a flat roof 6 m higher to account for the effect of downdrafts from wind flow over buildings. For the larger scale units stack heights of 15 m are typical.

<sup>c</sup> DEAT regulations specify; <0.5 mg/Nm<sup>3</sup> for each of Be, As, Pb, Cd, Cr, Ni, Sb, Ba, Ag, Co, Cu, Sn, Mn, and V, and <0.05 mg/Nm<sup>3</sup> for each of Hg, Cd, Tl.

gas alone was comparable to that in the laboratory (see Table 3), but the gas combustion efficiency dropped below that experienced in the laboratory (to 98.4%) and this illustrates the effect of training and suitable waste collection containers on performance in the field.

### 3.3. Phase 4: Selection of technical performance specifications for the Department of Health

In terms of technical performance specifications, exemptions from the full requirements of the regulations for handling, incineration and disposal of medical waste (South African Department of Water Affairs and Forestry, 1998) were motivated on the basis that remote rural primary healthcare clinics generate relatively small amounts of waste (less than 10 kg/week) and have needs and resources which differ significantly from those at healthcare centres in serviced areas. The motivations were given in terms of the minimum acceptable specifications which, based on the findings of the trials, are acceptable. Table 4 summarizes the proposed exemptions for performance specifications for under consideration by the Department of Health for the issue of tender specifications for the purchase of small-scale incinerators at remote rural primary healthcare clinics. More details, with a comparison to conventional large-scale incinerators, are given in the final report on the trials (Rogers and Brent, 1999).

## 4. Conclusions

The South African trials were successful in that a number of indicators were highlighted, which can be used for the future. The performance tests of the small-scale incinerators demonstrated that this mechanism of primary healthcare waste treatment is an improvement over previous

typical practices, i.e., open pit or drum burning, and dumping at uncontrolled community waste disposal sites. From the trials it can also be concluded that the small-scale incinerators have a high acceptability amongst primary healthcare clinic staff, Department of Health inspectors, and the community as a reliable alternative for medical waste treatment and disposal services that are often not accessible in remote rural areas of Africa. The reliability, however, is a function of the maintainability of the units in the rural areas, as well as the availability of the required fuel to operate the incinerators efficiently. Furthermore, suitably sized collection containers should be provided to reduce the possible overloading of the equipment, i.e., standardised containers that easily fit inside the chosen incinerator. These types of incinerators pose significant occupational health and safety hazards and strict compliance with operational requirements, including safety measures, must be adhered to. Therefore, the operators of small-scale incinerators must be trained adequately and monitored regularly for compliance. The incinerators should subsequently be used within the context of a safe waste management programme that provides the necessary resources in the form of collection containers, maintenance support, acceptable support energy, and understandable operational instructions for the incinerators.

This waste management programme must be supported by the supply of appropriate small-scale incinerators that have been laboratory tested on the type of waste to be burnt in the field. If the waste composition changes significantly, e.g., the addition of products of conception, then the operating procedures and emissions performance should again be checked in the laboratory, to predict the performance in the field. It is specifically noted that the formation of complex organic substances, e.g., dioxins and furans, are currently excluded from the laboratory tests



and are not included in the risk analyses. Similar to studies that have been conducted on large-scale incinerators (Alvim-Ferraz and Afonso, 2005), it is therefore proposed that a comprehensive set of emission factors should be established for small-scale incinerators for different waste compositions.

Finally, the trials confirmed that if these small-scale incinerators are used within the loading and geographical placement constraints, environmental impact assessment studies might not be necessary for licensing of individual units. The loading capacities of these small-scale incinerators will allow for the handling of medical waste during mass immunisation campaigns in South Africa, being acceptable in rural locations through an inclusive process of dialogue between all stakeholders.

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