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To: WHO WASH coordinators in Ebola-affected countries
WHO Ebola-Waste and IPC Expert Groups
WHO Geneva
NGO stakeholders

From: Jorge Emmanuel, PhD
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UNDP Medical Waste Experts

Re: **Assessment and Recommendations Regarding Management of Ebola-Contaminated Waste**

We apologize for the late report. In addition to one of us becoming sick, our schedules in Liberia, Guinea, and Sierra Leone and subsequent UNDP-related work kept us quite busy.

First of all, many thanks to Christophe Valingot and Hassan Srour (WHO Liberia) for facilitating our visits to SKD (both the German Red Cross and IRC ETUs), the MOD ETU, the 6000 m^3 wastewater holding tank, Redemption Hospital, and Island Clinic ETU in Liberia. Thanks also to the Ministries of Health of all three countries as well as WHO, MSF, and other organizations in Guinea and Sierra Leone for facilitating our visits to ETUs and hospitals treating Ebola-infected patients in those countries. It was essential for us to see the actual situation on the ground and the challenges we all face.

This report and appendices cover the following topics: Page

We hope the information and recommendations in this report will be used in updates and revisions of WHO's guidance "Ebola Virus Disease (EVD): Key questions and answers concerning health-care waste" which was completed last December and sent to the expert group last February 4, 2015.

1. Estimates of Ebola-waste generation rates

Information on generation rates of Ebola-contaminated waste is very limited. Appendix A presents two attempts at estimating the rates. One is based on measurements conducted for one day and obtained by WHO (Hassan Srour, Liberia) at Island Clinic, Liberia. The following waste generation rates were estimated using assumptions given in Appendix A:

- 1.9 waste bags total per Ebola patient per day (including non-infectious waste in the green zone)
- 390 liters of total waste (infectious plus non-infectious, red and green zones) per Ebola patient per day
- 1.2 infectious waste bags per Ebola patient per day (excluding estimated non-infectious waste in green zone)
- 240 liters of infectious waste per Ebola patient per day (excluding estimated non-infectious waste in green zone)
- 27 kg of infectious waste per Ebola patient per day (excluding estimated non-infectious waste in green zone)

Another method of estimation, also provided in Appendix A, is based on simple experiments to determine the volume of PPE waste from anecdotal reports that 7 to 8 sets of PPE per Ebola patient per day are used. The calculations indicate about:

- 230 liters of infectious PPE waste per Ebola patient per day

2. Assessment of current medical waste management practices

In the ***green zones*** of hospitals treating Ebola patients, we found instances of:

- improper sharps waste management
- poor waste segregation
- lack of color coding
- no use of plastic bags for collecting infectious waste

- no cleaning and disinfection of bins even when visibly contaminated with blood
- improper handling of Ebola-contaminated waste
- improper temporary storage of infectious waste; the storage sites did not meet the basic requirements in the Blue Book
- inadequate treatment system (see next section)
- collection of potentially infectious liquid effluents in open channels
- no healthcare waste management (HCWM) policies
- no written procedures, plans or roadmap on HCWM
- no HCWM committees or coordinators
- no training on HCWM
- no related policies, plans, organization, or training on infection control and prevention.

The findings in the hospitals are typical of hospitals in many developing countries in Africa. They indicate a very poor or non-existent healthcare waste management system before the Ebola crisis that was exacerbated by the crisis itself.

The photos below give examples of some of the problems listed above.

Figure 1. Sharps waste on the grounds of hospitals treating Ebola patients in Liberia (left), Guinea (middle), and Sierra Leone (right)

Figure 2. Single-use sharps containers reused with no decontamination; note lack of cleanliness and physical integrity of containers

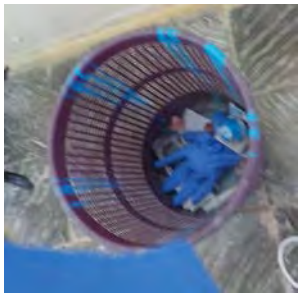


Figure 3. Infectious waste bins used with no color-coding, no labeling, and no plastic bags

Figure 4. Lack of color-coding of infectious waste bags and boxes at a hospital in Guinea

Figure 5. Examples of poor segregation (blood-contaminated waste found in general waste containers)

Figure 6. Storage area for regular (non-infectious) waste; note birds, blood-contaminated waste, recapped needle, and other sharps

Figure 7. Regular (non-infectious) waste, food items and PPE, scattered on the grounds of a hospital

In the ***red zones*** of Ebola Treatment Units, we found instances of:

- improper handling of Ebola-contaminated waste; waste workers inside the red zone of ETUs were manually carrying Ebola-contaminated waste instead of using covered carts, wheeled bins, covered wheelbarrows, or trolley-barrels.
- improper temporary storage of infectious waste including overflowing open waste pits with no roofs or protection from birds or rodents
- inadequate treatment system (see next section)
- no healthcare waste management (HCWM) policies or procedures
- little or no training on HCWM.

Because of limited space in two ETUs, the burn pits, which also served as burial pits, were located in the green zone. A door or opening on the fence at the back of the ETUs led to the burn/burial pit in the green zone about 3 meters from the door in one case and about 10 meters from the door in the second case. The photos below give examples of some of the problems listed above.

Figure 8. Improper (manual) handling of Ebola-contaminated waste in the red zone of an ETU

Figure 9. Left - worker manually dumping Ebola-contaminated waste into the burn/burial pit in the *green zone* of the hospital (note residences and residents in the background and the potential for wind to blow away some of the waste); Right - photo showing the distance between the red zone in the background and the location of the burn/burial pit from where the photo was taken at an ETU

Figure 10. Improper storage of sharps and other infectious waste at a hospital that had treated Ebola patients in Liberia; note cat in right photo (circled)

Figure 11. Open wastewater channels in the green zone (left) and red zone (right) of two ETUs

3. Assessment of waste treatment

Many community care centers for the isolation and management of Ebola patients (CCCs), as well as hospitals and clinics that are entry points for Ebola patients reportedly lacked healthcare waste treatment systems. For those that had some method to handle waste, we observed several common methods for treating Ebola-contaminated waste.

a. BURIAL PITS

One method was the use of burial pits, many of which were overflowing. Some of the waste pits were full of vultures and other birds. None of the waste pits met the basic requirements in the WHO Blue Book.

Figure 12. Overflowing Ebola-waste pit in the red-zone of an ETU; note vultures around the pit

Figure 13. Overflowing waste pits with partially burned waste and some waste blown away by the wind at an ETU

b. BURN BARRELS AND BURN PITS

The other common methods used were small burn barrels, open burn pits, and large burn skips. The small burn barrels reportedly lasted only a few months. In one ETU, several corroded burn barrels could be seen next to

the burn pit. There were attempts to direct the smoke up a small chimney. In most cases, smoke and other toxic fumes could be seen spreading to the surrounding communities. In one ETU, the smoke was visible from several hundred meters away.

The photos below illustrate conditions related to the burn barrel and burn pits.

Figure 14. Burn barrels and burn pit in the red zone of an ETU; the yellow colored building behind the wall a few meters from the burn pit (center photo) is the ward for confirmed Ebola patients; photo on the right shows two previous burn barrels used

Figure 15. Large burn skip on the green zone (left) and red zone (right) of an ETU; the two red zone burn skips (right photo) were about 15 meters from the Ebola patient wards

Figure 16. Open burn pit in the green zone just outside the red zone of a new ETU in Sierra Leone

The distances from the burn barrels, burn pits, or large burn skips to the Ebola patient wards ranged from only a few meters away to 20-30 meters away. Because of the dangers of fire, waste workers monitored the burn barrels and burn pits from a distance of 3-4 meters away, far enough to prevent their PPE from catching on fire. They would add kerosene when the fire died down. In one case, the health worker in the red zone of the ETU would exit a back door in the fence to dump Ebola-infected waste into an open burn pit in the *green zone* a few meters from the boundary of the red zone. The wind would sometimes blow some of the waste outside the edges of the pit. Once or twice a day, a waste worker would pour kerosene and burn the waste. Because of waste moisture content and the inefficiency of an open burn pit, the waste workers would at times have to add more kerosene and re-start the burning. Depending on the wind direction, smoke would blow towards the

nearby decontamination tent about 5 meters away, or the PPE donning area and entrance to the red zone about 10 meters away, or the visitor shack and Ebola patient ward about 12 meters away, or community residences about 30 meters away.

Calculations were made to estimate potential health impacts on waste workers and patients (see Appendix B). Table A summarizes estimates of the concentrations of 10 micron particulate matter (PM10), carbon monoxide, and HCl at a height of a waste worker standing 3 meters away as well as at the level of a patient lying on a hospital bed different distances away from a burn barrel. Average meteorological data from the three countries in November 2014 were used along with observations made of the burn barrels at various ETUs. The concentrations are compared with U.S. Occupational Safety and Health Administration (OSHA) Permissible Exposure Levels (PELs). Values at or exceeding the PELs are highlighted in red.

Table A. Estimates of Combustion By-Product Concentrations (10 micron particulate matter, carbon monoxide, hydrogen chloride) Near Burn Barrels

Distances	Estimated Concentration PM10 (mg/m^3)	OSHA PEL PM10 (mg/m^3)	Estimated Concentration CO (ppm)	OSHA PEL CO (ppm)	Estimated Concentration HCL (ppm)	OSHA PEL HCl (ppm)
Waste worker at 3 meters	15	15	29	50	9	5
Patient at 4 meters	84		162		50	
Patient at 10 meters	17		33		10	
Patient at 15 meters	8		16		5	
Patient at 20 meters	5		10		3	
Patient at 28 meters	3		6		2	

These estimates indicate that burn barrels and burn pits should be *at least* 20 meters away from patient wards, any common working or resting areas for health workers, and community residences.

c. INCINERATORS

Many ETUs were supplied with incinerators or were slated to receive incinerators. However, the specifications used to procure incinerators were inadequate. We recognize that the procurement was done under emergency conditions requiring immediate availability of equipment. Nevertheless, specifications for a higher level of incinerators would have been more beneficial. Many of the issues with the new incinerators relate to design specifications.

Based on our observations at ETUs, the key factors that could have been considered in the procurement of waste treatment technologies are:

I. Fire hazards related to PPE use near incinerators

- Tyvek, Tychem, and other similar PPE used by healthcare and waste workers dealing with Ebola-infected patients are highly flammable and are not heat resistant. Most of these PPE are made of high density polyethylene (HDPE) with a liquid-resistant coating that melts at 98°C. At this temperature, the seams of some PPE begin to open.
- Moreover, HDPE has a flash ignition point of 343°C. At this temperature, materials begin to burn spontaneously.
- The PPE material has a heat release capacity of about 1560 J/g-K. Materials with heat release capacities > 380 J/g-K exhibit self-sustained combustion.
- The incinerator chamber operates at a minimum temperature of 850°C.
- **CONCLUSION**: The healthcare or waste worker wearing PPE cannot go too close to the incinerator when the door is opened. Due to the flammable properties of PPE, standing near the door when depositing waste and if the wind shifts suddenly in the direction of the worker could result in the PPE igniting followed by self-sustained combustion with the likely consequence of injuring or killing the worker.

Because of the fire hazard, we observed the use of makeshift elevated wooden platforms used to push Ebola-contaminated waste from a distance into the incinerator. The series of five photos in Figure 16 were taken at a hospital that had treated Ebola patients and was temporarily shut down. The hospital was provided with a new oil-fired incinerator (Inciner8 model I8-200) to treat a few hundred bags of Ebola-infected waste that had accumulated. The left side of the photo (facing the door of the primary chamber) could be considered the red zone, while the right side (with the control panel box and the counterbalancing weight to open the door) could be considered in the green zone.

As shown in the photo, the main operator (a volunteer aid worker standing on the wooden platform on the left) opted to replace the flammable full-cover PPE with work coveralls and a face mask *thereby increasing his risk of exposure to Ebola*. After placing the Ebola-infected waste (yellow bags) on the platform, he picked up a long wooden stick. As the assistant operator in the green zone (on the right) pushed down on the counterbalance weights to open the primary chamber door, the main operator used the stick to push the yellow bags across the platform towards the open primary chamber. When the waste dropped into the chamber, the main operator then moved away quickly from the heat as the assistant operator closed the door. The main operator then splashed water on the smoldering wooden platform and stick to prevent them from catching fire.

There is a serious risk that a waste bag could get caught in the gap (about 150 mm) between the wooden platform and the incinerator opening. This could cause the bag to start burning and spill Ebola-contaminated waste onto the ground.

Figure 17. Operator (left side) in the red zone with heat resistant clothes pushing Ebola-contaminated waste in yellow bags into the incinerator as another operator (right side) in the green zone pushed down on the counterweight to hold the door open

II. High burning rates with PPE waste

- High density polyethylene (HDPE), of which the PPE is made of, has a heating value of 46.3 MJ/kg. This is almost the same heating value as gasoline or kerosene. Thus, a medical waste bag full of PPE would release a large amount of heat that could easily exceed the incinerator's combustion air capacity. This would result in the inability of the primary chamber to provide enough oxygen and of the secondary chamber to reduce the products of incomplete combustion resulting in a lot of heavy smoke.
- **CONCLUSION**: Whenever the waste content inside the primary chamber is comprised primarily of PPE (large amounts of which are generated in an ETU), the levels of air pollution including black smoke will be high. This may cause some resistance among local communities located near the incinerators who are impacted by the smoke and acid gases (hydrogen chloride).

The photos in Figure 17 show heavy black smoke after the addition of yellow bags. Since the yellow bags could not (and should not) be opened beforehand, it is impossible to estimate heating values of waste bag contents making it difficult to control the burn rate.

Figure 18. Heavy black incinerator smoke from the short stack of the new incinerator after addition of Ebola-contaminated waste; note fire coming out of the doors

III. Anticipated high levels of hydrogen chloride, polychlorinated dioxins and furans due to high chlorine use

- Hypochlorite is used extensively in the ETUs for cleaning, disinfection, and decontamination of PPE as health workers leave the red zone. Healthcare waste in general has high chlorine content, involving both organochlorine products such as PVC in intravenous bags and tubing as well as inorganic chlorine sources. Hence, one should expect various hazardous combustion byproducts including chlorine, hydrogen chloride (HCl), and polychlorinated dibenzo-dioxins and furans. The presence of the acid derivative HCl upon condensation and dissociation of hydrogen chloride gas in contact with moisture in the air is often seen in medical waste incinerators burning highly chlorinated waste in the form of a white haze or white smoke forming some distance from the stack. Although dioxin/furan stack sampling and testing are not possible, the high levels of HCl are a strong indication of high dioxin levels also.
- **CONCLUSION**: Whenever the waste content has high levels of hypochlorite and other chlorine sources, significant amounts of hydrogen chloride and chlorinated dioxins/furans should be expected.

Figure 19. White haze (circled) forming after the stack indicative of HCl emissions

IV. Lack of compliance with international standards for medical waste incinerators

- None of the incinerators viewed or proposed for the three countries complied with international standards for medical waste incinerators including the Best Available Techniques (BAT) guidelines under the Stockholm Convention for Persistent Organic Pollutants to which all three countries are parties. BAT

requires chlorinated dioxin/furan emissions no higher than 0.1 ng I-TEQ/Nm^3. To achieve this standard, certain primary and secondary measures are needed including the following key measures:

1) Primary chamber operating at 850°C and higher
2) Secondary chamber with a minimum residence time of 2 seconds after the last injection of air and operating above 1100°C for highly chlorinated waste at 6% O_2
3) Control of oxygen input (volume and distribution of primary and secondary air)
4) Online monitoring of temperature, oxygen content, carbon monoxide, and dust
5) Combination of air pollution control devices:
    a) Dedusting technologies (fabric filters, electrostatic precipitators, etc.)
    b) Dioxin emission reduction technologies (wet or dry scrubbers, gas quenching, catalytic oxidation, etc.)

- A commonly accepted engineering practice is for incinerator chimneys (also called stacks or flues) to be at least 9 meters above ground level and 3 to 6 meters above the highest point of adjacent buildings.
- The WHO Policy Paper on safe health-care waste management (2004) recommends support of the Stockholm Convention.

<u>LIBERIA</u>

- In Liberia, the following UK incinerators were procured:
    - Seven incinerators with a burn rate of 65 kg/hour. Based on limited information obtained about the small incinerators, it seems that although the incinerators can meet the temperature requirements, they have only a 0.5 second residence time in the secondary chamber and no air pollution control and hence they do not meet measures (2) and (5). This would render them incapable of significantly reducing smoke and pollutant emissions to international standards.
    - Two incinerators with a burn rate of 150 kg/hr. Based on limited information obtained, these incinerators can achieve the required temperatures and use additional fans to control air distribution, but they have a residence time ranging from 0.5 to 2 seconds and have no air pollution control devices.
    - Four incinerators with capacities of 150 and 200 kg/hr. These incinerators apparently meet measures (1) and (2) above but have no air pollution control devices. The photos in Figures 16 and 17 are of one of these incinerators and the consequences of the lack of air pollution control are obvious.
    - Technical specifications provided with one of the incinerators misleadingly reported dioxin emissions of 0.0 *mg* per Nm^3 but dioxin limits in TEQ should be less than 0.1 *ng* per Nm^3, a factor of a thousandth smaller!
    - All the incinerators had chimneys of about 1.5 m height, some of which were well below the heights of adjacent buildings.
    - The refractory and/or door in one new incinerator was broken, preventing the incinerator door from closing properly, allowing flames to come out of the door when it was supposed to be close. To make matters worse, the heat escaping from the chamber apparently caused the door frame to warp making it even more difficult to close. It was not clear if the broken refractory

was due to poor quality of manufacturing or materials, damage during shipment, improper curing process during installation, or operator error.

GUINEA

- In Guinea, 24 incinerators are being procured (17 for use outside Conakry plus 7 more):
    - The incinerators were developed in Germany for less developed countries but do not meet international standards.
    - The primary chamber operates between 600 to 800°C, below the requirements in measure (1) above.
    - The secondary chamber reportedly achieves temperatures >1000°C but no information is provided regarding the residence time which is likely below 2 seconds.
    - There is no control of primary and secondary air as required in measure (3).
    - There are no air pollution control devices as required in measure (5).
    - The manufacturers note that burning chlorine-containing compounds may generate HCl and dioxins. The manufacturers erroneously claim that since the flue gas exits the chimney at temperatures of 400 to 500°C, the "chance of dioxin recombination is almost cero [sic]." Studies have shown that de novo synthesis of dioxins takes place as the flue gas cools past the chimney. The manufacturers recommend removing from the waste any PVC (polyvinyl chloride plastics such as intravenous bags). Removal of contaminated PVC from infectious waste bags should not be allowed since Ebola-contaminated waste bags should not be opened.
    - These incinerators have 6 meter chimneys and may not be below the heights of the nearest buildings.

SIERRA LEONE

- In Sierra Leone, we were able to see only a few incinerators:
    - One UK incinerator I8M-60 provided to one hospital can meet measures (1) and (2) but does not have any air pollution control devices (measure (5)) and has a chimney that is at or lower than the roof height of the Ebola patient ward nearby.
    - The above-mentioned incinerator was new and never used. The hospital staff informed us that the incinerator was installed by the manufacturer who left just before the ETU became operational. However, according to the hospital staff, the installers never tested the incinerator, never left any operating instructions, never trained the waste workers on its use, and never trained the staff technicians on its maintenance.

Figure 20. Chimney of an incinerator several meters *below* the top of a nearby building (partially covered by smoke)

Potential health impacts on patients, operators, and health workers

Ebola patients, incinerator operators, and health workers are susceptible to acute exposures to incinerator pollutants. Smoke can irritate the eyes and airways. Fine particles in smoke (2.5 microns and smaller) can aggravate heart and lung conditions. Short-term exposures to hydrogen chloride and other acid gases from incineration may cause irritation of the eyes and respiratory tract as well as delayed breathing difficulties. Carbon monoxide exposure reduces oxygen delivery to the tissues, heart, brain, and other organs. At high levels, it can cause headaches, vomiting, and nausea.

Incinerator operators, health workers, and the public may experience adverse impacts from chronic exposure to pollutants if the incinerators are used frequently and for a long time. Dioxins and furans have been linked to cancers, developmental and reproductive effects, and impacts on the immune system. Long-term exposure to fine particles increases the risk of cardiopulmonary mortality and lung cancer. Incinerators release polycylic aromatic hydrocarbons which have been associated with various cancers and can produce reproductive, neurologic, and developmental effects. Heavy metals commonly found in incinerator emissions, such as lead, cadmium, and mercury, also have chronic health impacts at trace levels. Thus, numerous epidemiological studies of incinerator workers and residents living near incinerators have shown higher rates of various cancers, birth defects, and other health problems.

A WHO study of small incinerators for healthcare waste considered “best practice” incinerators—that is, properly operated and maintained incinerators with sufficient temperatures and afterburners—and assessed their health risks at low usage (used for only 1 hour per month), medium usage (used for 2 hours per week), and high usage (2 hours per day).[1] While recognizing uncertainties in the model, the study suggested that exposures from high usage could exceed an acceptable WHO limit for cancer risk. When compared to the US EPA cancer risk levels, both medium and high usage of “best practice” incinerators would not be acceptable. The study also looked at “expected practice” incinerators (those that are improperly designed, constructed, operated or maintained) and worst-case incinerators (those without an afterburner) which were unacceptable.

[1] S. Batterman, “Assessment of Small-Scale Incinerators for Health Care Waste,” prepared for Water, Sanitation and Health, Protection of the Human Environment, World Health Organization, Geneva, 21 January 2004.

d. AUTOCLAVES

Filoviruses are relatively fragile and can be inactivated by low heat. Heating to 60°C for 1 hour provides a good margin of safety for the inactivation of Ebola, Lassa and Marburg viruses. Ebola virus concentrations were reduced by 99.999% at 60°C in 22 minutes, and in 37 minutes for Lassa and Marburg viruses.[2] Autoclaves use pressurized steam typically in the range of 121° to 134°C and hence can effectively destroy the Ebola virus. Unlike incinerators, autoclaves do not release smoke, particulates, carbon monoxide, hydrogen chloride, nor highly toxic chlorinated dioxins and furans.

The United Nations Development Programme's Bureau for Policy and Programme Support expanded on a successful UNDP GEF Project by initiating a Global Project on Ebola Response entitled "Building national and local capacity for the treatment of healthcare waste in countries impacted by the Ebola epidemic" in Liberia, Guinea, and Sierra Leone. The project forms part of the overall UNDP Ebola Crisis Response and Resilience Programme (ECRRP), in particular, supporting the sub-priority areas "Providing Essential Support to the Health Sector" and "Equipment, Supplies and Infrastructure support to the health sector".

Previously, UNDP in partnership with WHO and the NGO Health Care Without Harm, implemented between 2008 and 2014, a project funded by the GEF on "Demonstrating and Promoting Best Techniques and Practices for Reducing Health-Care Waste to Avoid Environmental Releases of Dioxins and Mercury" in Argentina, Latvia, Lebanon, India, Senegal, Philippines and Viet Nam. As part of the project, non-incineration technologies were promoted in the project countries. An important component of the project was the design and development of a pressurized steam sterilizer (autoclave) to treat infectious waste. The sterilizer was specifically designed for the needs in Sub-Saharan Africa (low cost, safe, easy maintenance, easy operation, few moving parts, and no generation of smoke, dioxins, acid gases, carbon monoxide, particulates, and other incinerator pollutants). The technology was tested and produced in partnership with a South African autoclave manufacturer – Medi-Clave.

Figure 21. Medi-Clave (South Africa) autoclave sterilizer (left) and waste collection trolley with barrel

The key features of the African-made technology are as follows:

- The autoclave uses pressurized steam at 134-135°C alternating with vacuum cycles to achieve high levels of sterilization. It was tested with sterilizing indicators and bacterial spores far more resistant than the Ebola virus. Microbial destruction exceeded the international STAATT II standard for medical waste by

[2] Mitchell, SW and McCormick, JB. Physicochemical inactivation of Lassa, Ebola, and Marburg viruses and effect on clinical laboratory analyses. Journal of Clinical Microbiology. 1984: 20(3), 486-489.

an order of magnitude (that is, the Medi-Clave unit achieved a Log 5 reduction of *Geobacillus stearothermophilus* spores placed in double sealed plastic bags in the center of infectious waste loads).

- The technology has multiple safety features to protect workers and the environment.
- The autoclave is certified by a government-approved, independent Third Party as complying with international pressure vessel standards.
- The technology uses a simple mechanical control wheel instead of computer controls that are vulnerable to power outages and difficult to repair with low technical resources.
- Vacuum is achieved using a steam ejector with no moving parts, ensuring that air released from the equipment is disinfected. The vacuum enhances steam penetration and removes odors.
- The autoclave uses electricity (but can also be designed to run on diesel or LPG).
- The autoclave uses less than 20 liters of water per cycle. There is no chimney, only a drain pipe.
- Installation takes about a day if concrete pad, electrical, water and drain connections are already available.
- The residue—a dry, sterile, hard, compact mass less than half the original volume—is much cleaner (from a microbial perspective) than household waste. Using a post-treatment shredder further reduces waste volumes by as much as 85%.
- The system includes a specially designed trolley with a covered horizontal barrel that allows waste workers to pick up infectious waste bags from red zones and transport the waste to the autoclave with minimal handling. The entire barrel slides into the chamber for sterilization. This process reduces the workers' risk of exposure to pathogens.
- The technology is built in the South African firm Medi-Clave, which can provide technical support to countries in the continent and can build local capacity for equipment maintenance in the countries.
- The technology was adapted from the Medi -Clave units used to sterilize medical and surgical instruments for the past 14 years.
- The basic autoclave unit costs between 14,000 to 19,000 USD depending on numbers purchased. This price does not include shipment costs, barrel trolleys, and other optional accessories.

Because of inordinate delays and mistakes in the shipment of crates from Accra to the Ebola-affected countries, the first two units, which had arrived in Accra on November 18, 2014, were not shipped as complete units until more than a month later and were not fully installed and tested until the end of the year when UNDP experts had already left. The installation engineers also had to leave before final tests were completed due to the holiday season. The first two units were placed in No. 34 Military Hospital and Hastings/PTS 2 in Sierra Leone.

Figure 22. First autoclave unit during installation at No. 34 Hospital, Freetown, Sierra Leone

As of early February, the No. 34 Hospital autoclave was not used. The Hastings/PTS 2 autoclave was used regularly except during fuel shortages (which affected the generator set used to run the autoclave). Some issues, such as minor water leaks and lack of heavy duty gloves for operators, were found during a subsequent mission by a UNDP expert. He addressed the lack of supervision, need for improvement in waste handling practices by the operators, the need to improve working conditions under the hot sun, and the importance of documentation (filling in a treatment log book and results of daily tests) and traceability of treated waste. Since there was very little time between the long overdue arrival of the equipment and its quick installation, more follow-up is needed to ensure that the equipment is used and maintained properly.

4. Recommendations related to healthcare waste management

GENERAL RECOMMENDATIONS

- The Ebola crisis should be used as an opportunity to raise the level of healthcare waste management in each of the three countries to international standards. This will build resilience in the countries in facing future Ebola or other epidemics.
- Healthcare waste management should be closely linked to infection control and prevention which also needs to be enhanced in each of the three Ebola-affected countries. Indeed, after one year facing the Ebola crisis, many lessons have been learnt, many recommended practices have been brought to the affected countries and need to be capitalized on. In this framework, WHO and CDC are planning to set up strong and sustainable national programs for infection prevention and control (IPC) in each of the three countries. It would be therefore logical and desirable that these national programs benefit from the achievements and gains of the UNDP/GEF project.
- Healthcare waste management is an important part of all IPC programs, and its improvement requires efforts on the national and local levels, including the following approaches used in UNDP GEF projects on healthcare waste, as modified to meet each country's specific needs:
    - <u>POLICY, REGULATIONS, AND ROADMAP</u> [as guided largely by and in agreement with those of the CDC and especially WHO]
        - Promulgation of national policies and regulations

- Development of a national roadmap or plan towards achieving a high level of healthcare waste management, including specific achievable objectives or milestones with measurable indicators, set timelines, list of responsible parties, and a budget.
    - National situational analysis including the use of the UNDP GEF Individualized Rapid Assessment Tool (I-RAT), WHO national Rapid Assessment Tool, or similar tools (e.g., Dr. Ndoye's simplified I-RAT tool)
    - Development of partnerships and raising funds
    - Training at the national, sub-national and local levels
    - Procurement and maintenance of material resources
    - Internal and external communication
    - Stakeholder participation and community involvement
    - Application of a quality and continuous improvement approach
    - Regular (quarterly) monitoring and evaluation of the plan by the national committee and working group (see Organization)
- Using a system of incentives and disincentives
    - Awards and recognition of health facilities that have achieved high levels of healthcare waste management (e.g. most improved I-RAT score)
    - Awards and recognition of individual champions (advocates) that have promoted good healthcare waste management in their facilities or organizations
    - Requirement of a minimum level of healthcare waste management as a condition for accreditation or licensing
    - Monitoring and enforcement mechanisms, including penalties for violations
- Promulgation of administrative orders at the health facility level defining the composition, roles, responsibilities and operations of the appropriate committees, coordinator, subcommittees (working groups or individual) dealing with healthcare waste, and the physician in charge of blood exposures.
- Each health facility should have written plans and procedures for healthcare waste management including
    - Layout and flow of the waste
    - Written procedures on waste management, from classification and segregation to treatment and disposal
    - Communications (segregation posters, informational handouts)
    - Periodic training
    - Procurement plan and budgeting for equipment and consumables

o <u>ORGANIZATION</u>

- Creation of a national-level committee in the Ministry of Health to deal with healthcare waste management (this could be part of the national committee dealing with infection control and prevention)
- Creation of a multi-disciplinary, multi-sectoral national working group coordinated by the Ministry of Health with the participation of environment and other ministries, NGOs,

private sector, health professional organizations, and other relevant stakeholders to provide recommendations on the national policy, plan, and roadmap

- Replication of the above structures at appropriate sub-national or regional levels
- Each health facility should have a committee dealing with infection control and patient safety including healthcare waste management.
    - The committee should be headed by the administrator with day-to-day activities managed by a coordinator; the role of the committee is to translate national and sub-national policies and guidelines into specific practices in the facility.
    - The committee should include a healthcare waste management subcommittee, working group or individual (depending on the size of the facility) responsible for healthcare waste management, including implementation of specific procedures, training, monitoring and corrective actions, monitoring of equipment and consumable products for healthcare waste management, and monthly meetings and quarterly reporting to the committee.
    - There should also be a designated physician in charge of emergency response to blood exposure accidents from needle-stick injuries and infectious waste spills in the facility.
- Facilities should encourage the development of individual environmental champions or advocates who will promote healthcare waste management within their hospitals, departments, and organizations.

o <u>HEALTHCARE WASTE MANAGEMENT SYSTEM AT THE FACILITY LEVEL</u>

- This refers to a set of detailed procedures and routines integrated and institutionalized at the facility level. The system must include:
    - Proper procedures for waste classification, segregation, waste minimization, containers, color coding, labeling, posters and signs, handling and collection, internal transport, storage, treatment, disposal of solid healthcare waste
    - Collection and treatment of liquid waste
    - Written policies, roles and responsibilities; written procedures, roadmap, contingency plans
    - Periodic multi-level training
    - Organization (see Organization above) and development of environmental champions
    - Incentives (awards, bonuses) and disincentives at the facility level
    - Monitoring, evaluation, corrective action, and continuous improvement
    - Documentation
    - Annual budget and allocation of human resources; procurement of equipment and consumables
    - Periodic checking and maintenance of equipment.

SPECIFIC RECOMMENDATIONS

- The countries may take a model replication approach as has been done in various UNDP GEF healthcare waste projects. This approach entails the following:
    - Transformation of a small number of carefully selected health facilities into model / demonstration health facilities to pilot healthcare waste management best practices and new technologies
    - Using the pilot facilities to obtain data on costs, how to make the healthcare waste management system sustainable, and learn lessons on what succeeds and what fails
    - Using the demonstration facilities to showcase best practices and technologies to encourage other health facilities to follow
    - Replicating the model facilities nationwide using a phased approach, beginning with the larger hospitals above a pre-determined bed size then expanding further to the smaller hospitals; in some countries, a geographic approach may work better, beginning with the major cities and expanding further into small cities and rural areas.

5. Recommendations related to incineration

GENERAL INTERIM RECOMMENDATIONS ON INCINERATION

- Procurement specifications should meet international standards, in particular the BAT guidelines under the Stockholm Convention and at least the key primary and secondary measures listed above, in order to protect public health. The air pollution control devices should be designed to handle highly chlorinated waste. Bidders or manufacturers should provide air emission test results from burning typical medical waste following international test protocols—in particular, EN 1948 or US EPA Method 23—and the test results should include detection limits for dioxins and other pollutants. The tests should be conducted by an independent third party laboratory that is accredited and certified. Long-term continuous monitoring tests results are preferable to short-term sampling. US and EU emission limits are given in Table B below for comparison with test results.
- Because of the highly variable heat content of Ebola-contaminated waste, the incinerator specifications should require a means for controlling combustion air, such as forced draft fans or induced draft fans, or at least a barometric damper system.
- Because of the heterogeneity of medical waste, the incinerator specifications should include a waste feeder that can control the introduction of waste. The waste feeder opening should be close to ambient temperature to allow waste workers in proper PPE to deposit the waste safely.
- The incinerator specifications should require a minimum 9 meter chimney (stack) and if the installation site is known ahead of time, a chimney height that is 3 to 6 meters above the highest level of adjacent buildings should be specified. A higher chimney will also help increase draft in the incinerator.
- For incinerator operation, the operating temperature of the primary chamber should not go below 850°C especially during the addition of waste, and the set point temperature of the secondary chamber should be at 1100°C or higher with good oxygen control.
- Sample technical specifications are given in Appendix C.

Table B. US and EU Emission Limits for Incinerators

Pollutant	Unit	Standard conditions[a]	US EPA emission limits			EU emission limits		
			Small[b]	Medium[b]	Large[b]	Daily ave.	Half-hour ave.[c]	0.5–8-hour ave.
Particulate matter or total dust	mg/m³	20 °C, 101.3 kPa, 7% O_2, dry	66	22	18			
		273 °K, 101.3 kPa, 11% O_2, dry				10	10, 30	
Carbon monoxide	ppm(v)	20 °C, 101.3 kPa, 7% O_2, dry	20	1.8	11			
	mg/m³	273 °K, 101.3 kPa, 11% O_2, dry				50	100[d]	
Dioxins/furans	ng TEQ /m³	20 °C, 101.3 kPa, 7% O_2, dry	0.013	0.014	0.035			
	ng TEQ /m³	273 °K, 101.3 kPa, 11% O_2, dry						0.1[e]
Gaseous and vaporous organics as total organic carbon	mg/m³	273 °K, 101.3 kPa, 11% O_2, dry				10	10, 20	
Hydrogen chloride	ppm(v)	20 °C, 101.3 kPa, 7% O_2, dry	15	7.7	5.1			
	mg/m³	273 °K, 101.3 kPa, 11% O_2, dry				10	10, 60	
Hydrogen fluoride	mg/m³	273 °K, 101.3 kPa, 11% O_2, dry					1	2, 4
Sulfur dioxide	ppm(v)	20 °C, 101.3 kPa, 7% O_2, dry	1.4	1.4	8.1			
	mg/m³	273 °K, 101.3 kPa, 11% O_2, dry					50	50, 200
Nitrogen oxides	ppm(v)	20 °C, 101.3 kPa, 7% O_2, dry	67	67	140			
	mg/m³	273 °K, 101.3 kPa, 11% O_2, dry					200	200, 400
Cadmium	mg/m³	20 °C, 101.3 kPa, 7% O_2, dry	0.017	0.0098	0.00013			
Cadmium and thallium	mg/m³	273 °K, 101.3 kPa, 11% O_2, dry						total 0.05
Mercury	mg/m³	20 °C, 101.3 kPa, 7% O_2, dry	0.014	0.0035	0.0013			
	mg/m³	273 °K, 101.3 kPa, 11% O_2, dry						0.05
Lead	mg/m³	20 °C, 101.3 kPa, 7% O_2, dry	0.31	0.018	0.00069			
Antimony, arsenic, lead, chromium, cobalt, copper, manganese, nickel, vanadium and their compounds	mg/m³	273 °K, 101.3 kPa, 11% O_2, dry						total 0.5

ave., average; EU, European Union; TEQ, toxic equivalent; US EPA, United States Environmental Protection Agency
Different standard conditions are defined for EPA and EU limits; corrections have to be made to convert between different standard temperatures and percentage oxygen.
EPA defines small incinerators as having a waste burning capacity ≤200 lbs/h, medium capacity as >200–500 lbs/h and large capacity as >500 lbs/h.
At least 97% of half-hourly average concentrations must meet the first value and 100% must meet the second value.
All half-hourly average concentrations taken in any 24-hour period must meet this value.
The sampling period for dioxins/furans must be a minimum of 6 hours and a maximum of 8 hours under the EU directive.
Sources: EPA (2011); European Parliament and the Council of the European Union (2000)

SPECIFIC INTERIM RECOMMENDATIONS ON EXISTING INCINERATORS

- Incinerators and burn barrels should be moved at least 20 meters away from patient wards, any common working or resting areas for health workers, and community residences as much as possible.
- Operating temperature set points should follow the temperature requirements in measures (1) and (2) if they are within the design capacity of the incinerator.
- Experiments should be conducted to determine the minimum distance that the waste worker with flammable PPE should be when the incinerator door is opened. The experiments could be done empirically using PPE held at the end of a long stick or using a temperature probe held at the end of a long stick and placed at different distances from the door. The measured temperatures can be compared to the melting temperature of the liquid resistant coating and the flash ignition temperature of the PPE. Tests should be conducted at worst case conditions (maximum radiative and convective heat flux), such as opening the door when the chamber has reached the highest temperatures after the addition of waste with a high caloric content and with artificial wind conditions at different velocities in the direction of the PPE or test probe. In addition, tests could also be conducted when the primary chamber is empty and at or above 850°C while the primary burners are still on. Ideally for the test, the wind velocity should be such that the flame front extends beyond the opening as seen in Figure 18.
- The openings for the primary chamber should be retrofitted with some assembly to eliminate the gap between the wooden ramp and the opening of top-loading incinerators. An example is shown in Figure 19 below.

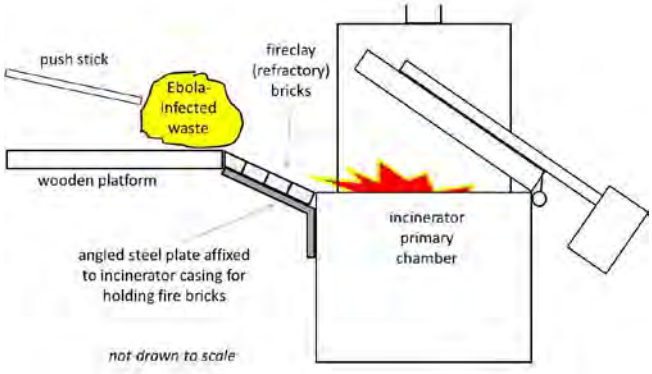


Figure 23. Example of a retrofitted assembly for safely feeding waste

- A better but more expensive solution is to retrofit the incinerators with side-loading primary chambers and sliding fire doors with mechanical all-enclosed waste feeders such a hydraulic ram-hopper feed system separated from the chamber by a fire door. This will allow controlled input of waste to improve combustion efficiency, reduced temperature transients during waste feed thereby lessening pollutant

emissions, and better protection of waste workers from heat, flames, and pollutants while allowing them to use full-cover PPE.

- In situations where incinerator stacks are too short compared to nearby buildings, incinerator manufacturers should be requested to extend the chimney height by adding stack sections or retrofitting where possible and reinforcing the taller chimney for stability.

6. Comparison of autoclaving and incineration

A comparison of the advantages and disadvantages of autoclaves (using Medi-Clave as the model) and incinerators (using the UK incinerators as models) is presented in the table below.

Table C. Comparison of Autoclaving and Incineration

	Autoclaving	Incineration
Throughput (kg per hour or liter per hour) for the same chamber capacity	Generally lower due to longer treatment cycle time	Generally higher
Space requirement	About the same	About the same, if air pollution control devices are excluded
Reduction in waste volume	Lower at 50-60%; 75-85% with shredding	Higher at 90-95%
Toxic air pollutants	No air pollutants, no stack; some odors from evaporation of sterilized liquids	Significant toxic air pollutants such as dioxins, furans, other organic compounds, carbon monoxide, particulate matter, acidic gases, heavy metals; emissions should meet international limits
Solid residue	Sterile mass, recognizable as medical waste unless shredded	Toxic ash, unrecognizable as medical waste; ash requires handling and disposal as hazardous waste
Liquid residue	Sterile condensate with some odors, must meet local effluent standards	Wastewater with dissolved or entrained pollutants if a wet scrubber is used for air pollution control; must meet international (dioxin) and local effluent standards
Energy use	Uses electricity (three phase power)	Uses electricity and diesel

Installation time	Shorter: 1 to 2 days	Longer: 5 to 7 days or longer depending on refractory curing procedure
Testing and commissioning	Microbial inactivation tests	Periodic stack testing under international standards
Ease of use	Computer-controlled units are highly automated; units with mechanical controls involve more operator attention but are less susceptible to outages and power quality problems	Computer-controlled units are highly automated; electronic controls are susceptible to outages and power quality problems
Maintenance, repair and equipment life	Periodic preventive maintenance recommended; replacement of door gasket is most common maintenance issue; up to 20 years if properly maintained	Periodic preventive maintenance recommended; replacement of refractories and burners are common maintenance issue; 10 to 15 years if properly maintained
Safety in relation to PPE use when feeding waste	No open flame; low heat; can be used safely with PPE	Open flames when primary chamber door is opened; high heat could ignite PPE
Acceptance by staff	Generally well accepted; technology familiar to central sterile supply staff	Accepted as traditional method; some concerns if smoke affects staff or patients
Acceptance by communities	No opposition	Opposition by some communities due to smoke
Equipment cost	Lower	Slightly higher without air pollution control; several times higher with air pollution control
Operating cost	About the same	About the same without air pollution control; several times higher with air pollution control
Commercial availability	Available in many countries including in Africa generally within 4-8 weeks	Widely available generally within 4-8 weeks

The following graphs[3] and data compare costs of autoclaves and incinerators that meet international standards.

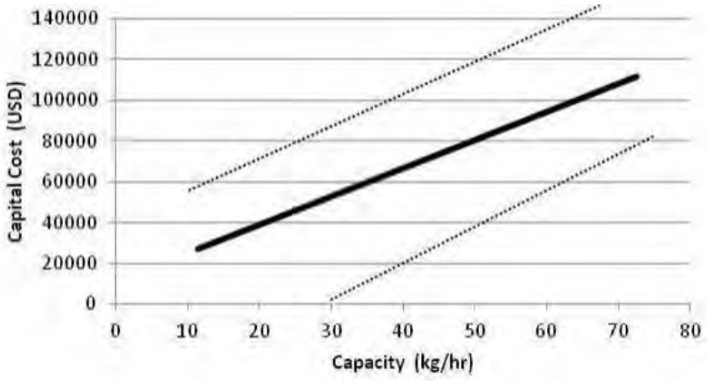


Figure 24. Range of capital costs of waste treatment autoclaves depending on throughput capacity (< 75 kg/hr)

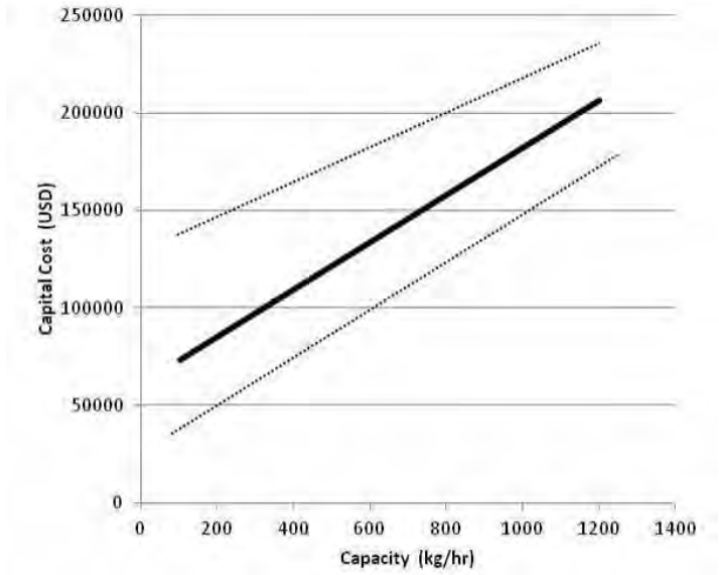


Figure 25. Range of capital costs of waste treatment autoclaves depending on throughput capacity (> 100 kg/hr)

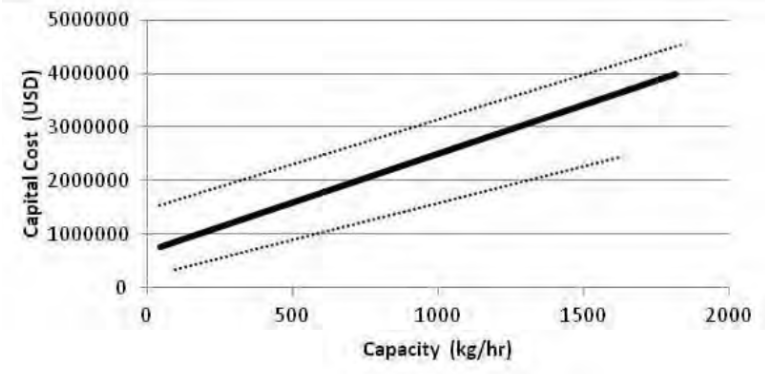


Figure 26. Range of capital costs of incinerators meeting international standards depending on throughput capacity

[3] From J. Emmanuel, *Compendium of Technologies for Treatment/Destruction of Healthcare Waste*, United Nations Environment Programme (Division of Technology, Industry and Economics), 2012.

The throughput capacities of waste treatment autoclaves range from 2 to 3,600 kg/hr with operating costs from 0.14 to 0.33 USD/kg. Incinerators with air pollution control range from 5 to 3,500 kg/hr with operating costs ranging from 0.27 to 1.66 USD/kg.

7. Recommendations related to autoclaving

GENERAL RECOMMENDATIONS

In keeping with the long-term strategy outlined in the WHO Policy on Safe Health-Care Waste Management (August 2004), non-incineration technologies (such as autoclaves) should be promoted to prevent the disease burden from exposure to dioxins and furans. Resolution WHA63.25 of the 63rd World Health Assembly (21 May 2010) calls for the transfer and use of appropriate technology for safe and environmentally sound waste management.

The report of the Special Rapporteur to the Human Rights Council of the UN General Assembly (A/HRC/18/31, 4 July 2011) recommends that "in so far as practicable, incineration as a disposal method of hazardous medical waste be substituted with more environmentally-friendly and safe methods of disposal. Autoclaving, for example, is an environmentally sound method to treat infectious waste that requires relatively low investment and operating costs." [Section V.F.95] The Special Rapporteur also recommends that "developing countries be provided with adequate financial and technical assistance to design, construct, operate and manage non-incineration medical waste treatment facilities." [Section V.F.96]

As more non-incineration technologies such as waste treatment autoclaves become available to the three countries, the medical waste incinerators should be phased out and replaced with non-incineration technologies.

At Ebola Treatment Units, use of the autoclaves should be prioritized to treat Ebola-contaminated waste with high chlorine content (such as PVC plastic intravenous bags and PPE previously soaked in chlorine solutions) while limiting the use of incinerators, burn barrels and open burn pits to waste with low chlorine content.

SPECIFIC RECOMMENDATIONS

- A system of supervision, periodic training, documentation, monitoring, evaluation, corrective action, and preventive maintenance should be put in place to ensure that waste treatment autoclaves are used properly and efficiently. Autoclave treatment should be integrated into an overall healthcare waste management system that deals with healthcare waste from generation to disposal.
- Table D shows the recommended sizes and number of units for Ebola Treatment Units, assuming 240 liters infectious waste per Ebola patient per day and 1.5 hours per cycle. After the Ebola crisis, the autoclaves can be transferred to regular healthcare facilities for the treatment of medical waste.
- Table E shows the recommended sizes and number of autoclave units for hospitals and other healthcare facilities, assuming 0.5 kg per bed per day (medium level of segregation), 0.15 kg/liter, and 1.5 hours per cycle.

Table D. Number and Size of Autoclaves for ETUs

ETU Beds	Size of Autoclave (liters)	Number of Autoclaves Needed	Operating Hours
10	175/350	1	21/10.5
25	350	2	13.5
50	350	3	18
75	350/600	4/2	20/22.5
100	350/600	5/3	21/20
150	350/600	7/4	22/22.5

Table E. Number and Size of Autoclaves Needed for Regular Hospitals and Healthcare Facilities

Number of Non-Ebola Hospital Beds	Size of Autoclave (liters)	Number of Autoclaves Needed	Operating Hours
25	175	1	1.5
50	175	1	1.5
75	175	1	3
100	175	1	3
150	175	1	4.5
200	175	1	6
250	175	1	7.5
300	350	1	4.5
400	350	1	6.0
500	350	1	7.5
1000	350	2	7.5

RECOMMENDED AUTOCLAVE DESIGN AND USAGE:

- During an Ebola crisis, a combination of two or more autoclaves could be used. As shown above, large-size autoclave units will be oversized for most hospitals and healthcare facilities after the Ebola crisis. Autoclaves can be run in parallel as modular units which can later be separated and installed in different healthcare facilities after the Ebola crisis.
- The following features of the existing Medi-Clave autoclave design are recommended for Ebola treatment units:
    - Mechanical controls placed at the back of the unit. This allows the operator to be in the green zone without having to wear PPE.
    - Locating the autoclave in the boundary of the red and green zones, such that the barrel trolley and waste feed door are in the red zone, and the rest of the autoclave in the green zone for easy maintenance and repair. (See Figure 27 below.)
    - A steam ejector to produce the vacuum thereby eliminating the vacuum pump and a long air-steam mixing section after the ejector to disinfect the extracted air.

- Mechanical controls to avoid problems with outages and power quality problems; mechanical controls also make it easier to maintain and repair.
- A closed barrel trolley to collect and treat waste; the barrel has an inner drum that rotates to allow treated waste to exit at the bottom.
- Instructions written on the control panel as a guide to operators.
- A sliding door or other easy to open door.

- Sample technical specifications are given in Appendix C.

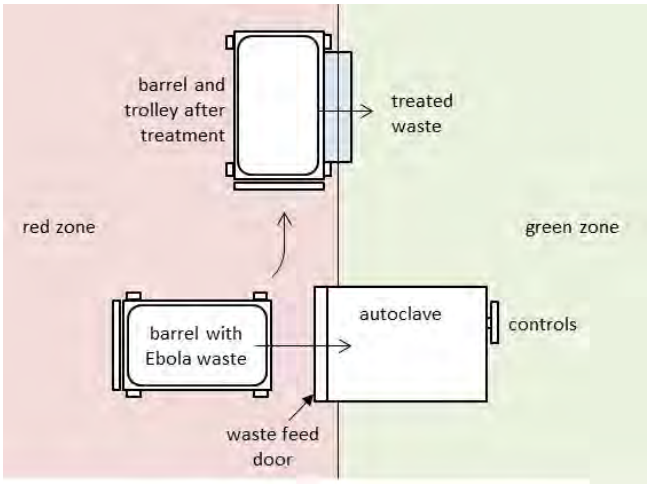


Figure 27. Typical layout of a waste treatment autoclave in relation to the red and green zones

- The following procedures for the use of the waste autoclave are recommended:
  - Challenge tests using biological tests and/or Class 5 steam integrators placed inside double bags to validate the operating parameters
  - Written operating procedures that are readily available to operators
  - Initial training followed by periodic training of operators
  - Supervision of operators; periodic monitoring and evaluation
  - Use of a Class 5 integrator as a challenge test with the first waste load of the day
  - Documentation of all treatment runs, including date, start and end times for *each* treatment cycle, name of the operator, result of the challenge test, operating parameters if different from the standard parameters, and any comments; if a weighing scale is available, the weights of the waste load can also be recorded.
  - After the waste is treated, the barrel trolley is removed and the waste is dumped into an inclined plane that allows the treated waste to roll out into the green zone through an opening in the boundary between the red and green zones, as shown in Figure 27.
  - Treated waste that does not contain any sharps can be handled as regular waste after treatment. Treated sharps waste should be buried unless a post-treatment shredder is used to destroy the sharps.
- The following features may present challenges in some situations:
  - As noted above, the capacity of the autoclave makes it difficult to handle large amounts of Ebola waste; Medi-Clave and other manufacturers can build larger autoclaves (350 liters or greater).

- The boiler uses three-phase power which may not be available in some locations. Other places may have limited kVA power and may require a generator set.
- The need for a concrete pad and flat horizontal surface to mount the autoclave and make it easier to guide the barrel trolley.
- A reliable source of clean water; hard water would require a water conditioning system provided as an option with the autoclave.

- The following autoclave design, while more expensive than the above-mentioned design, is especially suited at the start of an Ebola crisis.
  - 350 liter or 600 liter autoclave
  - Double-pass (double door) autoclave such that the waste feed door is in the red zone and the exit door for treated waste is in the green zone; this design allows the treated waste to come out directly into the green zone; it also makes it easier to install in that the autoclave can be assembled and tested in the green zone near the boundary with the red zone and when installation and commissioning are completed, the boundary can be modified to include the waste feed door in the red zone.
  - The barrel trolley would have to be modified to allow the sterile barrel to be passed through to the red zone after emptying the treated waste in the green zone.
  - Mechanical or electronic controls in the same side as the exit door for treated waste, that is, in the green zone.
  - In areas where electricity is not available, insufficient or unreliable, the boiler can be run on diesel or bottled gas, and the temperature gauges, lights and recording instruments can be run with a solar panel and a small storage battery. This arrangement however precludes the use of an electrical shredder for sharps waste.

8. Other recommendations

RECOMMENDATIONS REGARDING EBOLA-CONTAMINATED LIQUID WASTE

- The issue of what to do with Ebola-contaminated liquid waste was raised several times during the mission. In some cases, the liquid waste was channeled into a storage tank or concrete reservoir.
- In Liberia, plans were underway to collect Ebola-contaminated wastewater from ETUs and store them in a 6000 cubic meter concrete storage tank at a former wastewater treatment plant. It was not clear what to do with the liquid waste afterwards.
- The following are suggestions regarding Ebola-contaminated liquid waste:
  - Channels or canals with liquids potentially contaminated with Ebola should be covered to prevent people from accidentally stepping into the wastewater and prevent exposures.
  - For ETUs using storage tanks, experiments could be conducted to determine the required holding time for the Ebola virus to die out in contaminated wastewater stored in a tank or reservoir. The effect of temperature, pH, total suspended solids, biological oxygen demand, free chlorine level, etc. should be considered. Depending on daily volumetric quantities of wastewater generated in ETUs, a number of storage tanks could be set up to hold liquid waste alternatingly for the pre-determined holding time before being released.

- Another approach is to have two holding tanks, each capable of containing all the wastewater for at least a day. A 5 log reduction of Ebola virus can be achieved by heating the liquid to 60°C for 22 minutes. Therefore, heavy-duty tubular immersion heaters, stirrers and temperature probes could be carefully lowered into the tanks or reservoirs. At the end of the day, the wastewater could be channeled to Tank 2 while the heater and stirrer in Tank 1 could be turned on until the wastewater temperature measured near the bottom of the tank is at 60°C for about an hour, after which the tank could be allowed to cool and then emptied. The next day, the decontamination process is switched to Tank 2, while Tank 1 is allowed to fill up.

- For the 6000 m^3 tank, experimental data on holding times in smaller tanks could be used to estimate the required holding time in the 6000 m^3 tank. Storing the liquid waste for a sufficient time would be the simplest and cheapest method.
- An option to speed up reduction of the viral load is to use ozone, a disinfectant that is more effective than chlorine in destroying viruses. Ozone can be produced on site and used immediately. Ozone is hazardous to workers (permissible exposure limit = 0.1 ppm in air or 0.2 mg ozone per m^3 of air, 8-hour average) and explosive when it reaches a high concentration of 240 g/m^3. Appropriate safeguards would be needed. Virucidal properties are generally achieved at concentrations of 5 to 15 mg ozone per liter, with contact times of about 5 minutes. The treatment system would include an air compressor, ozone generator and cooling system, electricity, and some method of exposing the wastewater to the ozone gas. One approach is to use a circulation pump that takes wastewater from one end of the storage tank, passes the wastewater through a closed vessel into which ozone gas is fed to achieve the proper dose and contact time, and then pumped back into the other end of the storage tank. A simpler approach is to inject the ozone gas into the wastewater through a fine pore diffuser to allow the ozone bubbles to contact the liquid. The location of the diffuser should be changed periodically to ensure that ozone is well distributed to all parts of the storage tank.
- Instead of ozone, another method is to use UV radiation at 254 nm which has been shown to destroy the Ebola virus. A set-up similar to the one described above using a circulation pump and a closed vessel UV reactor to provide the required dose can be used. The estimated UV fluence (predicted by inactivation modeling) of the Ebola virus in liquid suspension resulting in a 63% kill, D_{37}, is 7.4 J/m^2.[4] The system would include a UV lamp (preferably a non-mercury LED lamp), closed reactor, ballast or controller, circulation pump, piping, and electricity. The reactor can be a non-contact reactor wherein the UV lamps are suspended outside a transparent conduit carrying the wastewater.

[4] Sagripanti JL, Lytle DC. "Sensitivity to ultraviolet radiation of Lassa, vaccinia, and Ebola viruses dried on surfaces," Arch Virol 2011; 156:489–494

NOTES REGARDING EBOLA INACTIVATION BY SUNLIGHT

- Filoviruses are very sensitive to inactivation by solar radiation, in particular, UV light at 254 nm. Filoviruses were reduced by 90% by the midday sun within 20 minutes in Hilo, Hawaii, USA and in 100 minutes in Griffin, Georgia, USA.[5]
- Using NASA data on surface UV irradiance in West Africa at noon from November 1 to 16, 2014, an estimate was made of solar degradation of Ebola in the affected countries (see Appendix D) using the method of Lytle and Sagripanti.[6] Estimates indicate that direct solar radiation at noon could result in a 90% reduction of Ebola virus in about 1.5 hours due to UV radiation.
    - This theoretical calculation suggests that storing infectious waste bags directly under the sun while awaiting treatment could help reduce Ebola virus concentrations on the outside surfaces of the plastic bags.
    - The calculation also suggests that drying PPE, bed sheets, mattresses, and other items directly under the sun after washing with detergent and disinfection could provide added assurance in decontamination.

RECOMMENDATIONS REGARDING CHLORINE DISINFECTION

- Ebola is a lipid enveloped virus that is easier to destroy then non-enveloped viruses. Therefore, disinfectants that are effective against non-enveloped viruses will be effective against Ebola. These disinfectants include 60-95% ethanol, 2% quaternary ammonium compounds, and 4-6% chlorine disinfectants. High concentrations of Ebola, Lassa and Marburg viruses in blood were inactivated by a 1:100 dilution of contaminated blood with 3% acetic acid (pH = 2.5) for 15 minutes.[7]
- All health facilities, government buildings, and commercial facilities have plastic containers by the door for hand hygiene. A 0.05% hypochlorite solution is generally used. Repeated exposure of skin to dilute solutions of hypochlorite often causes irritation, drying and cracking of skin. This situation could increase the risk of Ebola transmission through breaks in the skin.
- Hypochlorite solution quickly loses its effectiveness in the presence of dirt, oil, and organic matter.
- Where possible, the 0.05% chlorine solution should be replaced with alcohol-based hand rubs containing humectants to prevent drying of the skin. The hand rubs could be placed in dispensers at the entrance of the facilities. The following recommendations are made:
    - Local manufacturing of alcohol-based hand rub formulations can be based on the WHO recommended formulation (e.g., 80% ethanol, 1.45% glycerol, 0.125% hydrogen peroxide; all in v/v percent).[8]
    - The ethanol can be obtained from a variety of crop-based feedstock. Liberia makes a spirit distilled from sugarcane (Liberian rum or so-called cane juice or CJ) which is about 43% alcohol

[5] "Inactivation of filoviruses and disinfection protocols" Chapter 14 in Filoviruses: A Compendium of 40 Years of Epidemiological, Clinical, and Laboratory Studies, J Kuhn and CH Calisher, Springer Science & Business Media, May 29, 2008, pp 297-299

[6] C.D. Lytle and J-L Sagripanti,"Predictive Inactivation of Viruses of Relevance to Biodefense by Solar Radiation," *J. Virol* 79(22): 14244-14252 (2005).

[7] Mitchell, SW and McCormick, JB. Physicochemical inactivation of Lassa, Ebola, and Marburg viruses and effect on clinical laboratory analyses. Journal of Clinical Microbiology. 1984: 20(3), 486-489.

[8] "Guide to Local Production: WHO-recommended Handrub Formulation," World Health Organization, Geneva, revised April 2010.

by volume. Palm wine is made from the fermentation of the sap from pine trees in the forested region of Guinea. Sierra Leone has locally produced *omele*, a traditional sugar cane-based spirit. All these local spirits are made by fermentation of sugars. Distillation can further remove water and obtain a 96% v/v ethanol which can be used to formulate an alcohol-based rub. Technical assistance could be provided to convert local manufacturing of spirits to production of alcohol disinfectants.

- Hypochlorite solutions are unstable and degrade with time. Decomposition is accelerated by sunlight, elevated temperatures, and impurities such as copper and iron. For example, the half-life of a sodium hypochlorite solution of 200 g/liter available chlorite at 25°C is about 45 days when stored in the dark but drops to about 7 days when exposed to sunlight. For every 10°C increase in storage temperature, the decomposition rate increases by a factor of 3.5. The ideal storage temperature for hypochlorite is 15°C, which would be difficult in Africa. Sodium hypochlorite solutions at higher concentrations have faster decomposition rates. In all of the Ebola-affected countries, there were many instances in which large plastic vertical tanks (most likely polyethylene) containing hypochlorite solution were placed directly under the sun. These could result in rapid degradation due to heat and UV radiation from the sun. Ideally, plastic tanks stored outside should have UV protection and should be painted white.
    - In situations where translucent plastic tanks containing hypochlorite solution are stored outside, it is recommended that the tanks be kept under a shade by positioning a tarpaulin cover or roof over the tanks. This will keep the tanks cool and avoid direct sunlight.
    - For tanks holding hypochlorite solutions at high concentrations and stored under the sun, periodic tests should be done to ascertain that the level of available chlorine has not decreased significantly. The simplest and cheapest method is to use chlorine test paper capable of detecting the target range of free available chlorine. These chlorine test strips are chemically treated and change color depending on the amount of available chlorine. A color chart provided for comparison is used to estimate the concentration.

Figure 28. Large plastic containers of hypochlorite solutions under the sun

RECOMMENDATIONS REGARDING DONNING AND REMOVAL OF PPE

- In several ETUs, the consultants observed that hoods or head coverings were placed first, followed by goggles, masks and face shield. Thus, during removal of the PPE, googles, masks and face shields were removed before the hood, apron and coverall were taken off. This meant that protection of the mucous

membranes of the eyes, nose and mouth was compromised as the hood, apron and coverall were removed. The consultants found that it is possible to put the face shield inside the hood while retaining some air space below the shield for comfort.

- The updated WHO recommendation for PPE donning and removal should be reviewed at all ETUs and the proper sequence should be followed.

RECOMMENDATIONS REGARDING THERMOMETER CALIBRATION AND MAINTENANCE

- Portable temporal artery infrared (IR) thermometers or forehead thermometers were commonly used in healthcare facilities, government buildings, and commercial establishments to measure the temperature of people entering the facilities. These thermometers should have a maximum error of 0.3°C for a given black-body temperature range. The consultants observed that temperature measurements of the same individual using two different forehead thermometers sometimes resulted in large differences.
    - Temporal artery infrared thermometers should be certified to meet international standards such as ASTM E1865-98 (reapproved 2009).[9]
    - Temporal IR thermometers should be properly maintained and calibrated. Maintenance involves cleaning, battery testing, function testing, keeping a maintenance record, and testing for accuracy.[10] Thermometers that do not meet the ±0.3°C maximum permissible error should be returned to the manufacturer for adjustment.

[9] "Standard Specification for Infrared Thermometers for Intermittent Determination of Patient Temperature," ASTM E1965 – 98 (Reapproved 2009); J.A.M. Shimek, J. Emmanuel, P. Orris and Y. Chartier, *Replacement of mercury thermometers and sphygmomanometers in health care: Technical Guidance*, World Health Organization, Geneva, 2011.

[10] J. Emmanuel, "Guidance on Maintaining and Calibrating Non-Mercury Clinical Thermometers and Sphygmomanometers," UNDP GEF Global Healthcare Waste Project, July 2013.

APPENDIX A

1. Waste Generation Rate Estimate 1

Number of Bags of Solid Waste - Data from Island Clinic ETU (December 1, 2014) which uses more PPE than other ETUs

Time	Triage	Confirmed Ward	Recovery Ward	Exit Point	Green Zone	Total
4:30 am	2	3	2	6		13
9:00 am					16	16
11:00 am	2	3	2	6		13
3:00 pm					16	16
5:00 pm	2	3	2	6		13
8:00 pm					16	16
TOTAL						87

4 waste collectors in the Red Zone; 2 waste collectors in the Green Zone

Photo of typical bag:

Measured circumference = 70 inches
Measured height (excluding section for tying) = 45 inches
Measured width excluding folds = 28 inches
Measured double folds = 8 inches per side

Estimating volume using measured flat width and measured height
w = 28
h = 45
Robin equation for maximum volume with bottom single-edge seal:
Volume = w3 * (h/(PI*w) - 0.071 (1 - 10^(-2h/w)))
Volume = 9672 in3 or 159 liters

Estimating volume assuming cylinder with top and bottom hemispheres
circumference = 70 in
thus radius r = circumference/(2*PI) = 11.1 in
Height of cylindrical section = h - 2*r = 22.7 in
Volume of cylinder = PI*r^2*Height = 8859 in3
Volume of top & bottom hemispheres = 4/3* PI * r^3 = 5792 in3
Total volume = 14651 in3 or 240 liters

Therefore, use 200 liters as a reasonable approximation of the volume of the standard bag.
Number of patients during the measurement period (12/1/14) < 50

Number of patients on 11/25/15 = 40 patients

Assuming 45 patients on 12/1/14
Based on one-day sampling:
Number of bags per patient per day = 1.9 bags/patient per day
Assuming 200 liters per bag:
387 liters of total waste (infectious and non-infectious) per patient per day

Consider all waste in the red zone as infectious waste. Assume 70% of waste in the green zone is non-infectious.
173 liters infectious waste (red zone) per patient per day
64 liters infectious waste (green zone) per patient per day
1.2 bags of total infectious waste (red and green zones) per patient per day
Volume: 240 liters of infectious waste per patient per day

If all the waste at the exit point is assumed to be PPE waste and 8 PPE sets are used per patient per day (anecdotal information), and each PPE set is 0.48 kg (450 g per suit, 30 g for face mask, gloves, apron)
Then the density of waste bags in the exit point is: 0.043 kg/liter
Assume 0.15 kg/liter for non-PPE infectious waste

Mass of waste = 3600 liters x 0.043 kg/liter + 7080 x 0.15 kg/liter
Mass per patient: 27 kg of infectious waste per patient per day

2. Waste Generation Rate Estimate 2

PPE waste

PPE sets per patient	8	sets per patient per day (based on anecdotal information)
Estimated volume of PPE	29	liters per PPE set
		Based on measurements of a Tyvek suit, gloves and face mask rolled into a LOOSE ball (circumference = 120 cm)
Volume of PPE waste	233	liters PPE waste per patient per day

Volume: 230 liters infectious PPE waste per patient per day

APPENDIX B

Estimation of concentrations of pollutants from burn barrels at ETUs, focusing only on particulates, CO, and HCl

Assume 55 gallon drums (200 liters) used for burning

liters	kg/liter	kg waste
200	0.2	40

Emission Factors:

	kg/Mg	kg/kg	kg waste	kg pollutant	g pollutant	
PM10	19	0.019	40	0.76	760	(Ref: Evaluation of Emissions for the Open Burning of Household Waste in Barrels, US EPA, Report EPA-600/R-97-134a)
CO	42	0.042	40	1.68	1680	(Ref: Emission factor for open burning of municipal waste, AP-42, US EPA, 5th Edition)
HCl	16.8	0.0168	40	0.672	672	(Ref: Emission factor for uncontrolled incineration of medical waste, US EPA, 1995) Note: HCl may be underestimated since ETU waste will contain large amounts of hypochlorite

Burn duration with kerosene:	10	minutes =	600	seconds	based on observations of burn barrel at an ETU

Q = Point source emmission rate:

Q,PM =	1.267	g per second of particulates
Q,CO =	2.800	g per second of CO
Q,HCL =	1.120	g per second of HCl

Use steady-state Gaussian plume air dispersion model to compute concentration at bed of patient at different distances from the burn barrel and worker 3 meters away

Calculating momentum-dominated plume rise

DELH

S for Pasquill F class = 0.035*g/T(K)

g = gravitational acceleration =	9.81	m/s2
T = ambient temperature =	298.15	K
S =	0.0011516	

DELH = 1.5 * (V*R)^.667 * U^(-.333) * S^(-.1667)

R = barrel radius =	0.292	meters, based on standard diameter of 584mm
U = wind velocity =	0.8	m/s, see below
V = exit gas velocity =	0.3	m/s estimate

DELH = 0.089 meters

H = point source height = barrel height + DELH =	965	mm =	0.965	meters	based on height of standard drum barrel (876mm) plus plume rise from photos of 800mm
X = downwind distance of nearest patient =	28	meters =	0.028	km	
X, worker = downwind distance of worker =	3	meters =	0.003	km	Distance to worker monitoring the burning
Z = patient's vertical distance from ground level =	635	mm =	0.635	meters	based on average height of beds
Z, worker = worker's vertical distance from ground =	168.3	cm	1.68	meters	based on average Liberian female height 157.3 cm, and male/female ratio 1.07

Assume Pasquill atmospheric stability class = F (moderately stable atmosphere)

Constants for Pasquill stability F class (from US EPA, ISC air dispersion model)

a =	15.209	c =	4.1667
b =	0.8366	d =	0.36191

Standard deviations of concentration distributions in crosswind and vertical directions

	For nearest patient:	For nearest waste worker:
THETA = 0.017453293 * (c - d ln(x)), in radians =	0.05167	0.0658
SIGY = 465.11628 * x (in km) * tan(THETA), in meters =	0.67357	0.8579
SIGZ = a * X^b, in meters =	247.055	38.129

Average wind speeds:

Monrovia, Liberia	7.9	km per hr average over several years, based on Roberts Field data	2.2	m/s	
Freetown, Sierra Leone	6	miles per hour ave for December, Lungi airport data	2.7	m/s	
Conakry, Guinea	3	km per hr ave for November	0.8	m/s	Use conservative estimate

Steady-state Gaussian air dispersion equation, assuming no inversion aloft at centerline (Y=0)

Concentration = (Q / (2*PI*U*SIGY*SIGZ)) * [EXP((-(Z-H)^2)/(2*SIGZ^2) + EXP((-(Z+H)^2)/(2*SIGZ^2))]

							OSHA PEL		% of PEL
Concentration at worker location 3 meters from barrel									
Concentration of particulates =	0.0148093	g/m3	14.8	mg/m3			15	mg/m3	99
Concentration of carbon monoxide =	0.0327363	g/m3	33	mg/m3	29	ppm	50	ppm	57
Concentration of hydrogen chloride =	0.0130945	g/m3	13	mg/m3	9	ppm	5	ppm	176
Concentration at nearest patient bed if 4 meters away:									
Concentration of particulates =	0.0837276	g/m3	84	mg/m3			15	mg/m3	558
Concentration of carbon monoxide =	0.1850821	g/m3	185	mg/m3	162	ppm	50	ppm	324
Concentration of hydrogen chloride =	0.0740328	g/m3	74	mg/m3	50	ppm	5	ppm	995
Concentration at nearest patient bed if 10 meters away:									
Concentration of particulates =	0.0171083	g/m3	17	mg/m3			15	mg/m3	114
Concentration of carbon monoxide =	0.0378183	g/m3	38	mg/m3	33	ppm	50	ppm	66
Concentration of hydrogen chloride =	0.0151273	g/m3	15	mg/m3	10	ppm	5	ppm	203
Concentration at nearest patient bed If 15 meters away:									
Concentration of particulates =	0.0084992	g/m3	8	mg/m3			15	mg/m3	57
Concentration of carbon monoxide =	0.0187877	g/m3	19	mg/m3	16	ppm	50	ppm	33
Concentration of hydrogen chloride =	0.0075151	g/m3	8	mg/m3	5	ppm	5	ppm	101
Concentration at nearest patient bed if 20 meters away:									
Concentration of particulates =	0.0051804	g/m3	5	mg/m3			15	mg/m3	35
Concentration of carbon monoxide =	0.0114515	g/m3	11	mg/m3	10	ppm	50	ppm	20
Concentration of hydrogen chloride =	0.0045806	g/m3	5	mg/m3	3	ppm	5	ppm	62
Concentration at nearest patient bed if 28 meters away (standard ETU design):									
Concentration of particulates =	0.0029075	g/m3	3	mg/m3			15	mg/m3	19
Concentration of carbon monoxide =	0.0064271	g/m3	6	mg/m3	6	ppm	50	ppm	11
Concentration of hydrogen chloride =	0.0025709	g/m3	3	mg/m3	2	ppm	5	ppm	35
Calculated concentration at patient bed for different distances:									
Concentration of particulates =	0.0029075	g/m3	2.91	mg/m3			15	mg/m3	19
Concentration of carbon monoxide =	0.0064271	g/m3	6.4	mg/m3	5.6	ppm	50	ppm	11
Concentration of hydrogen chloride =	0.0025709	g/m3	2.6	mg/m3	1.7	ppm	5	ppm	35

APPENDIX C

Sample Technical Specifications

AUTOCLAVE THAT MEETS INTERNATIONAL STANDARDS

Equipment	Single- or double-pass vacuum autoclave specifically designed to treat medical waste
Capacity	_____ liters per run, or _____ kg/hr based on an estimated waste bulk density of _____ kg/liter
Working pressure	2 bars (30 psig) or higher.
Working temperature	121°C (250°F) or higher; 134°C (273°F) preferred.
Footprint	The autoclave system shall fit in a space of ____m x ____m x ____m height. Equipment and accessories shall be able to pass through a door opening of ____m width x ____m height.
Pressure vessel standard	The autoclave shall be certified to comply with ASME Boiler and Pressure Vessel Code Section VIII and/or European standard EN 13445 (including hydrostatic testing requirements) or equivalent national standard.
Safety feature – redundant overpressure features	Overpressure sensor linked to a pressure relief safety valve plus a rupture disc or equivalent pressure limiting device to keep the pressure below the maximum allowable pressure.
Safety feature – door interlock	Door interlock system to prevent opening door while vessel is under pressure; safety feature shall also prevent start-up if the door is not properly closed.
Safety feature – emergency shut-off	Emergency shut-off button or switch in a readily accessible location.
Safety feature – protection from hot surfaces	External insulation to prevent hot surfaces (exceeding 50°C) that may come in contact with workers.
Materials of construction	Materials in contact with steam shall resist attack from steam and condensate, not cause deterioration of the quality of the steam, and not release any substances known to be toxic in such quantities that could create a health or environmental hazard. The technology shall not have any asbestos, asbestos-containing substances, mercury thermometers, and mercury switches.
Microbiological inactivation efficacy	The autoclave system shall meet STAATT Level III microbial inactivation efficacy criteria at the operating parameters as shown by challenge test results (Criteria: 4 log reduction or higher of heat-resistant spores as demonstrated using *Geobacillus stearothermophilus* or *Bacillus atrophaeus*). A 5 log reduction is preferred.
Third Party Test Results	A copy of test results of microbial inactivation efficacy on the same model and capacity treating typical medical waste shall be provided. The tests should be conducted by an independent Third Party. Three samples of heat resistant spores shall each be placed in closed plastic bags and buried in the center or bottom of three separate plastic bags containing typical medical waste. All three samples should meet or exceed STAATT Level III at the operating conditions to be used by the autoclave.
Door	Single or double quick-opening door(s).
Electrical	_____ V, ____-phase, ____ Hz electrical power.
Electrical safety	The autoclave system shall meet the requirements of IEC 61010-2-040, UL 61010A-2-041, or an equivalent electrical safety standard; as well as the electromagnetic compatibility requirements under EN 61326:1997 or equivalent

	standard.
Controls	The autoclave shall be operated by mechanical controls or electronic controls that permit automatic operation using one or more pre-set operating cycles. Measurements of chamber temperature and pressure shall be fitted with a system that can recognize a broken temperature or pressure sensor. The control system shall include an emergency shut-down switch or button. For purposes of maintenance, testing, or in cases of emergency, means shall be provided to permit manual operation of the process. The autoclave shall be protected against the effects of electrical short circuits.
Display indicators	Pressure and temperature readable by normal vision from a distance of 1.00m.
Other indicator displays	Displays indicating: operation in progress and cycle complete; as well as fault condition.
Indicator for temperature	± 1% accuracy over the scale range 50°C to 150°C; 0.1°C resolution for digital instruments.
Indicator for pressure	± 1.6% over the scale range -1 bar to 3 bar; 0.01 bar resolution for digital instruments.
Indicators for time	Error not to exceed 1% of the indicated time in hours or minutes as applicable.
Fault condition	A means to return to atmospheric pressure shall be provided in the event of a failure of the controls. In the case of autoclaves with electronic controls, the controls shall show a visual indication of failure and an audible alarm if values of the process variables exceed the limits specified by the manufacturer, or if a failure occurs that prevents the completion of the process. A broken sensor shall cause a fault to be indicated.
Recording	Recording of time, temperature and pressure can be digital or analog and shall include values sufficient to confirm that cycle parameters have been achieved and maintained within the manufacturer's specified tolerances. Printed records should be readable for not less than 2 years. Time of 5 minutes or more shall have an accuracy of ±1% or better.
Vacuum	Minimum -0.25 bar within 4 minutes for pre-vacuum cycle and minimum -0.1 bar for drying cycle; the autoclave shall meet section 8.2.2 of EN 285:2006+A2:2009 (i.e., uniform color change throughout a Bowie-Dick indicator when tested on the empty autoclave). A steam ejector system is preferred. If the bidder offers a vacuum pump system as a means for achieving vacuum, a backup pump and critical spare parts shall be supplied.
Decontamination of air	Any air removed from the chamber during initial vacuum cycles shall be decontaminated by means of steam treatment, a HEPA filter (Class H13 or higher, EN 1822; or >99.97% efficiency on 0.3 micron particles, IEST-RP-CC001), HEPA with activated carbon filtration, or other decontamination method effective in preventing the release of pathogens into the workplace air.
Markings	Markings for safety shall comply with EN 13445 or ASME BPV Section VIII, EN 61010-1, and EN 61010-2-040 or UL 61010A-2041 or equivalent standards.
Required autoclave system components:	
High thermal efficiency steam generator or boiler	Shall comply with the ASME and/or EN standards for boilers.
	Shall include steam outlet, pressure gauge, relief valves in accordance to the standards, as well as an automatic water supply system or a manual supply with a visual water level tube

	Shall have a high thermal resistance and a minimum of 50 mm thickness and shall cover all surfaces with the potential for high heat losses from the boiler; Shall not contain asbestos.
	Shall be properly sized to meet the steam production demands of the autoclave
	Maximum working pressure of 8 bar
	Energy source: _____ (electricity, diesel oil, or gas)
	Shall include a safety pressure relief valve, automatic power shutoff in case of insufficient water, alarm in case of low or high water levels and overpressure, emergency shutdown button or switch that is easily accessible, and visual indicator of failure.
	The vendor shall be furnished with physicochemical tests of the water quality. The vendor shall specify the type, capacity, vessel size, flow rate, and other parameters of a water conditioning system for boiler water feed if needed, as well as the cost of such water conditioning system. The purchaser has the option to include the water conditioning system in the Purchase Order.
Autoclavable barrel and trolley	The vendor shall provide _____ sets of autoclavable barrels mounted on trolleys for ease of collection and treatment of infectious waste with minimal handling.
Spare parts for _____ year of operation (including autoclave door gasket).	
Other requirements:	
Operating and service manual in _____ language.	
_____ year warranty on parts and service after commissioning and acceptance.	
On-site training provided to operators as outlined in the Schedule of Requirements.	

INCINERATOR THAT MEETS INTERNATIONAL STANDARDS

Equipment	Medical waste incinerator
Capacity	_____ kg per hour based on an estimated waste bulk density of _____ kg per liter
Characteristics of waste	Widely varying composition as is typical of medical waste, with the following average characteristics unless specified otherwise below: - 5 to 30% moisture by weight - 5% maximum non-combustible solids - 15 MJ/kg average heating value - Approximate composition (27% paper, 40% plastics, 6% glass, 3% metal, 15% cloth and cellulosics, 9% other Specific data if available: _____
Combustion performance	The medical waste incinerator shall be capable of reducing waste to ash not exceeding 15% of the total combustible charges.
Outdoor installation	The medical waste incinerator will be installed outdoors and all incinerator components have to be suitable for outdoor installation, including totally enclosed electric motors, and corrosion and moisture protection.
Materials of construction	The incinerator shall not have any asbestos, asbestos-containing substances, mercury thermometers, and mercury switches. Refractory materials shall meet relevant standards under ISO TC33 and CEN/TC 187.
Types of incinerator design acceptable	Dual-chamber controlled air incinerator or dual-chamber pyrolytic incinerator
Waste feed system into the combustion chamber	Automatic charging ram or auger feed system that is capable of injecting small amounts of waste at frequent intervals and that prevents waste from being fed when the combustion chamber is less than 850ºC. The waste feed opening should be at or below 50ºC in an ambient temperature of 21ºC.

Primary combustion chamber	Constructed with a steel casing (reinforced to withstand internal pressures without deflection or damage to the refractory or other components) supported by a steel frame and provided with refractory bricks and insulation
Access doors, openings, and gaps	All access doors, openings, and gaps shall be sealed to prevent emission of smoke and exhaust gas and to block admission of air during incinerator operations. Doors exposed to flame or direct heat of combustion gases shall be lined with the same type and thickness of refractory and insulation as that used in the combustion chamber.
Grate system for the primary chamber	Moving grate, traveling grate, reciprocating grate, or rotating drum grate
Primary combustion chamber temperature	≥ 850ºC with no cold spots
Secondary combustion chamber	Constructed with an exterior steel casing (reinforced to withstand internal pressures without deflection or damage to the refractory or other components) and provided with refractory bricks and insulation
Secondary combustion chamber temperature	1100ºC or higher
Secondary combustion chamber residence time	≥ 2 seconds after the last injection of air in the secondary chamber
Primary and secondary burners	Separate electrically spark-ignited primary burners and secondary burners with automatic control shall be used to achieve the specified temperature requirements in the primary and secondary chambers. The flames of the primary and secondary burners shall not impinge on the incinerator walls or floor.
Energy source for burners	Diesel fuel oil
Air supply	Air supply in the primary and secondary chamber shall be regulated between 30%-80% and 170%- 120% of stoichiometric amount respectively. Suitable flow measurement devices shall be provided on the primary and secondary air ducting. The combustion air shall be supplied through a separate forced draft fan after accounting for the air supplied through burners.
Insulation	Insulation to be used for masonry, reinforced concrete, or non-combustible material shall prevent damage to the foundation from excessive heat and shall be of a thickness to limit the outer casing to 66ºC in an ambient temperature of 21ºC when the incinerator is operating at full capacity.
Refractory	Refractory shall be "super duty" and heat-resistant to a minimum of 1000ºC in the primary chamber and 1200ºC in the secondary chamber. Refractory shall also be abrasion resistant in the primary chamber, constructed of plastic or castable type refractory, designed to prevent bulging and destruction due to heat stress, capable of supporting more than twice the hourly burning rate and preventing leakage of fluids, and with a minimum thickness of 110 mm for walls and hearths. The manufacturer shall be responsible for curing the refractory during installation.
Electrical	_____ V, ____-phase, ____ Hz electrical power
Electrical safety	The medical waste incinerator shall meet the requirements of IEC 61010-2-040, UL 61010A-2-041, or an equivalent electrical safety standard; as well as the electromagnetic compatibility requirements under EN 61326:1997 or equivalent standard.
Physical safety	Belts, pulleys, chains, gears and other rotating parts as well as sharp edges, located where persons come in close proximity to them, shall be enclosed or guarded to protect personnel. High-temperature surfaces and piping located where they could endanger personnel or create a fire hazard shall be covered with insulation.
Noise level	The noise level at 305 mm from any incinerator component shall not exceed 85 dBA.
Controls and instrumentation	The medical waste incinerator shall include control equipment and instruments, controls for burners and fans, time clocks, relays, operating switches, indicator lights, gauges, motor starters, fuses, alarms, and circuit elements of the control system, and other controls and instruments necessary for operation of the incinerator.
	The operation and regulation of the medical waste incinerator shall be done from a

	central console. The console shall include a visual graphic (screen) and computer recording to automatically monitor and record dates, time of day, batch number and operating parameters.
	The medical waste incinerator shall include continuous online monitoring for combustion control including temperatures in both chambers, oxygen content, CO, CO_2, total organic carbon (TOC), moisture, and particulate matter (total dust) in the gaseous emission, measured at every one minute interval or less.
	The control system shall include an emergency shut-down switch or button. The system shall be protected against the effects of electrical short circuits.
	The control system shall prevent waste charging if the primary and secondary chambers are outside of their specified temperature ranges, and in the event of unsafe conditions—including failure of the combustion air fan, ID fan, or recirculation pump; and abnormal conditions at the air pollution control devices.
	Automatic control circuit systems and manual switches shall be interlocked to prevent hazardous conditions or the discharge of toxic air pollutants above the specified limits.
	The control system shall use proportional control or other effective control algorithm to maintain the operating conditions specified herein.
	The controls and instruments shall be mounted on one or more free-standing control panels conveniently located and placed to allow operators to effectively monitor incinerator operations.
Temperature measurement	The medical waste incinerator shall have an indicating recording pyrometer for measuring incinerator temperature with a range of -18 to 1315ºC accurate to within ± 1% of range.
	The medical waste incinerator shall have thermocouples to measure gas temperatures and control burner operation, suitable for temperatures up to 1260ºC and accurate to within 0.5% of the operating and indicating temperature range.
Display indicators	Temperature and other key parameters readable by normal vision from a distance of 1.00m.
Other indicator displays	Displays indicating: operation in progress and fault conditions.
Indicators for time	Error not to exceed 1% of the indicated time in hours or minutes as applicable.
Fault condition	In the event of a failure that prevents the completion of the process, the controls shall show a visual indication of failure and an audible alarm.
Air pollution control	The medical waste incinerator shall be equipped with air pollution control devices, including de-dusting equipment and additional pollution reduction equipment, sufficient to meet the air emission limits specified in these specifications. The following de-dusting equipment are acceptable: Fabric filters operating < 260ºC High temperature ceramic filters Cyclones Electrostatic precipitators at 450ºC High performance adsorption unit with activated charcoal Other _____ The following additional emission reduction equipment are acceptable: Catalytic oxidation Gas quenching Catalytic oxidation Catalyst-impregnated fabric filters Wet scrubber with lime solution Dry scrubber with mixtures of activated carbon, lime, limestone Moving bed and fluidized bed reactors Fixed bed reactor with activated carbon Entrained flow or circulating fluidized bed reactor with activated carbon/lime or limestone followed by fabric filters Other (specify) _____

Air emission limits	The medical waste incinerator shall be equipped with air pollution control devices, sufficient to meet the following air emission limits: DAILY AVERAGE VALUES: Total dust: 10 mg/m^3 Carbon monoxide: 50 mg/m^3 Gaseous and vaporous organic substances, expressed as total organic carbon: 10 mg/m^3 Hydrogen chloride: 10 mg/m^3 Hydrogen fluoride: 1 mg/m^3 Sulfur dioxide: 50 mg/m^3 Nitrogen monoxide and nitrogen dioxide, expressed as nitrogen dioxide: 200 mg/m^3 10-MINUTE AVERAGE VALUE Carbon monoxide: 95% - 150 mg/m^3 HALF-HOURLY AVERAGE VALUES: Total dust: 100% - 30 mg/m^3, 97% - 10 mg/m^3 Carbon monoxide: 100% - 100 mg/m^3 Gaseous and vaporous organic substances, expressed as total organic carbon: 100% - 20 mg/m^3, 97% - 10 mg/m^3 Hydrogen chloride: 100% - 60 mg/m^3, 97% - 10 mg/m^3 Hydrogen fluoride: 100% - 4 mg/m^3, 97% - 2 mg/m^3 Sulfur dioxide: 100% - 200 mg/m^3, 97% - 50 mg/m^3 Nitrogen monoxide and nitrogen dioxide, expressed as nitrogen dioxide : 100% - 400 mg/m^3, 97% - 200 mg/m^3 AVERAGE VALUES OVER A SAMPLING PERIOD >6 HOURS TO 8 HOURS: Dioxins and furans: 0.1 ng I-TEQ/Nm^3 AVERAGE VALUES OVER A SAMPLING PERIOD >30 MINUTES TO 8 HOURS: Cadmium and its compounds: Total 0.05 mg/m^3 Thallium and its compounds: Total 0.05 mg/m^3 Mercury and its compounds: 0.05 mg/m^3 Antimony and its compounds: Total 0.05 mg/m^3 Arsenic and its compounds: Total 0.05 mg/m^3 Lead and its compounds: Total 0.05 mg/m^3 Chromium and its compounds: Total 0.05 mg/m^3 Cobalt and its compounds: Total 0.05 mg/m^3 Copper and its compounds: Total 0.05 mg/m^3 Manganese and its compounds: Total 0.05 mg/m^3 Nickel and its compounds: Total 0.05 mg/m^3 Vanadium and its compounds: Total 0.05 mg/m^3 Standard conditions defined as T = 273ºK, P=101.3 kPa, 11% O_2, dry gas
Third Party Test Results	A copy of test results from stack sampling and analysis of air emissions from an incinerator of the same model and capacity burning typical medical waste shall be provided. The tests should be conducted by an independent Third Party duly accredited and certified. The test report should include concentrations of 17 congeners of 2,3,7,8-TCDD/F, corresponding detection limits, Toxic Equivalent (TEQ) using I-TEF as well as TEQ from non-detected congeners and the maximum possible TEQ (estimated maximum possible concentration/upperbound), sampling standard recoveries, extraction standard recoveries, and other quality assurance/quality control information.
Stack (chimney)	The stack shall have a minimum height of 9 meters above ground level and not less than 2.5 times the height of the nearest structures. (Height of nearest structure, if

	known: _____ m) The stack shall have vertical and lateral supports to withstand wind forces of _____ kph. A sampling port and platform shall be provided. The sampling port shall be at least 8 stack diameters downstream from any flow disturbances such as a bend or contraction, and at least 2 stack diameters away from any upstream flow disturbances.
Emergency bypass	The emergency bypass shall remain closed and shall not permit the release of gaseous emissions during normal operations. The date, time and duration of the opening of the emergency bypass during abnormal conditions shall be recorded and included in the permanent record.
Bottom ash handling	The incinerator shall include a wet ash sump with additional means to prevent bottom ash from being released into the workspace.
Painting and finishing	The inner surfaces of the outer casing of the incinerator, the exterior surfaces of the outer casing, the control panel, and piping, except corrosion-resistant steel, shall be cleaned to the base metal for removal of oil and rust before primer is applied. A weather resistant finish shall be placed on all items that will be exposed to the outside.
Recording	Recording of operating parameters can be digital or analog and shall include values sufficient to confirm that cycle parameters have been achieved and maintained within the manufacturer's specified tolerances. Printed records should be readable for not less than 2 years.
Typical service life	10 years
Spare parts for one year of operation	
Operating and service manual in _____ language.	
One (1) year warranty on parts and service after commissioning and acceptance.	
On-site training provided to operators	

APPENDIX D

Estimating solar degradation of Ebola virus in West Africa
(N.B. This information has not been confirmed experimentally and should be used cautiously.)

From: Lytle and Sagripanti (2005) "Predictive inactivation of viruses of relevance to biodefense by solar radiation

J Virology 79(22) 14244-14252

Ebola Data

Predicted D37 (J/m2)	7.4	for UV at 254nm
UV for 1 log reduction (J/m2)	17	for UV at 254nm

Lytle and Sagripanti calculated effective solar flux spectra at different SZAs (their Figure 3)

at 28 deg SZA: 0.0007 W/2/nm effective solar flux

						Time zone	elevation (m)
Monrovia, Liberia			degrees	minutes	seconds	0	28
latitude	6.3133	N	6	18	48		
longtitude	10.8014	W (negative)	10	48	5		
Freetown, Sierra Leone						0	26
latitude	8.4844	N	8	29	4		
longtitude	13.2344	W (negative)	13	14	4		
Conakry, Guinea						0	22
latitude	9.5092	N	9	30	33		
longtitude	13.7122	W (negative)	13	42	44		
						average elevation	25.3

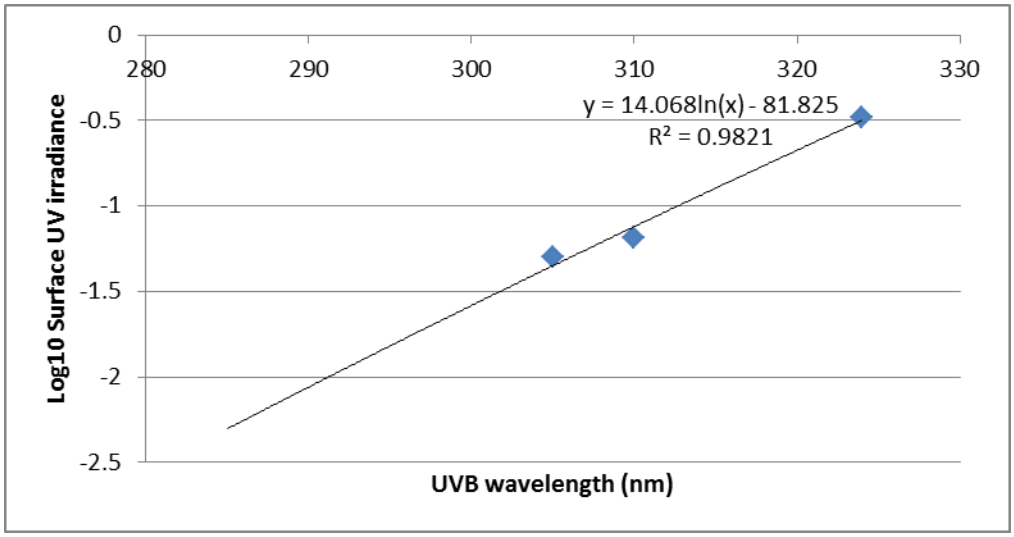
http://aa.usno.navy.mil/data/docs/AltAz.php

	time	altitude	azimuth	SZA = 90-altitude
Monrovia: For November 17	12:00	63.7	164.8	26
	12:30	64.7	181	25
Freetown: November 17	12:00	61	161.3	29
	12:30	62.4	176	28
Conakry: November 17	12:00	59.8	161	30
	12:30	61.4	175.2	29

	Noon time SZA
Liberia	26
S/L	29
Guinea	30
Average	29

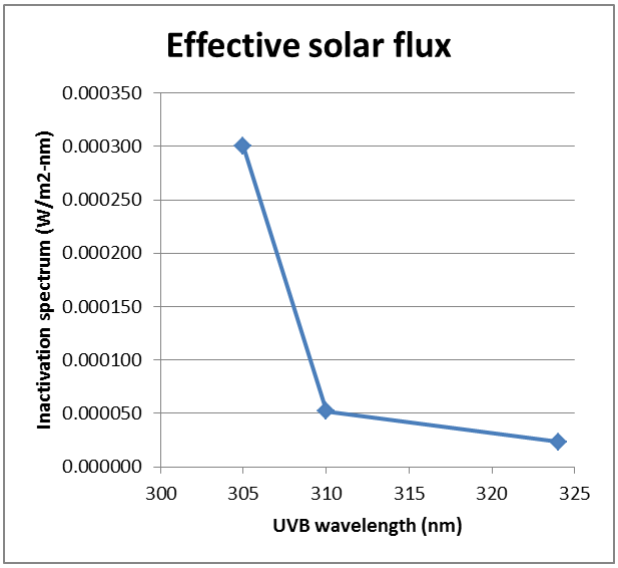
DATA from NASA GES DISC for November 1 to 16, 2014

OMI/Aura Online visualization and analysis of OMUVBd.003



UV wavelength nm	noon surface UV irradiance in West Africa	Log10 of UV irradiance	UV irradiance W/m2-nm	UV sensitivity relative to 254 nm*	UV wavelength nm	virus inactivation effective spectrum W/m2-nm
380	650	-0.187086643	0.65			
324	330	-0.48148606	0.33	0.00007	324	0.000023
310	65	-1.187086643	0.065	0.0008	310	0.000052
305	50	-1.301029996	0.05	0.006	305	0.000300

*From Fig 1 in Lytle & Sagripanti



Assume the same shape as in Figure 3 of Lytle and Sagripanti for 28 degrees SZA

(Extrapolating data results in less conservative figures)

Area of a trapezoid with base1 (295-310 nm) and base2 (300-305) and height .0003

Area = 0.5 * (base1 + base2) * height

Total effective solar flux =	0.003	W/m2 or
	0.18	J/m2-min

Therefore,

SZA	Dates	Elevation	Eff solar flux	UV (J/m2) for 1log red	Time for 1 log red (min)
29	Nov 1-16, 2014	25	0.18	17	94