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Best Environmental Practices and Alternative Technologies for Medical Waste Management

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Abstract

The spread of bloodborne pathogens in health-care waste motivated the World Health Organization to issue a policy in 2004 calling for the development of national policies, guidances, and plans for health-care waste management. The policy paper, however, also recognizes the risks associated with incineration, which in developing countries can be problematic due to the lack of capacity for emission testing or regulatory enforcement. The Stockholm Convention highlights the problem and requires the use of best environmental practices and best available techniques. Examples of best environmental practices, including segregation, waste minimization, handling, storage, and transport, are presented. The paper describes non-incineration alternative technologies including autoclaving, advanced steam systems, microwave treatment, and alkaline hydrolysis. For developing countries where sharps waste is a public health threat, for example, the use of reusable sharps containers, central autoclaving, post-treatment shredding, and recycling does away with single-use sharps containers and eliminates the need for landfilling. A Global Environmental Facility project will demonstrate and promote best practices and technologies in eight countries in order to virtually eliminate environmental releases of dioxins and mercury from health care. It will be a valuable tool for raising awareness and disseminating information on environmentally sound health-care waste management.

Introduction

Improper management of health-care wastes from hospitals, clinics, and other health facilities poses occupational and public health risks to patients, health workers, waste handlers, haulers, and communities. In developing countries, scavenger families who make a living of recycling materials from open dumpsites are at great risk especially from sharps waste. The World Health Organization (WHO) estimates that unsterilized syringes cause between 8 to 16 million cases of hepatitis B, 2.3 to 4.7 million cases of hepatitis C, and 80,000 to 160,000 cases of HIV every year.[1] While many of these cases are due to inadequate sterilization and reuse of syringes, anecdotal data indicate that numerous needle-stick injuries that could spread bloodborne pathogens occur among waste workers and children due to improper disposal.[2] Other sharps waste, such as glass ampoules, pose similar risks. An incident in Russia illustrates the danger: children playing with waste bins near a health center were infected with live strains of smallpox from exposure to discarded ampoules of the vaccine.[3]

The lack of national policies or guidelines on health-care waste management in many developing countries exacerbates this problem. On August 2004, the World Health Organization issued a policy paper calling on developing countries and countries in transition to develop national policies, guidance manuals, and implementation plans for the sound management of health-care waste.[4] A few years earlier, in May 2001, the Stockholm Convention on Persistent Organic Pollutants was adopted by 151 countries. The Stockholm Convention called for the reduction and, where feasible, the ultimate elimination of persistent organic pollutants such as polychlorinated dioxins and furans which are emitted by medical waste incinerators. (A paper on the Stockholm Convention and its requirements dealing with medical waste incinerators is also presented at this conference.)

Health Risk Assessment of Small Incinerators

For decades, small-scale incineration was the method of choice of health facilities for the treatment of infectious waste. The WHO policy paper of 2004 and the Stockholm Convention, however, raised a dilemma, namely, the need to consider the risks associated with the incineration of health-care waste.

A medical waste incinerator releases into the air a wide variety of pollutants depending on the composition of the waste. These pollutants include particulate matter such as fly ash; heavy metals (arsenic, cadmium, chromium, copper, mercury, manganese, nickel, lead, etc.); acid gases (hydrogen chloride, hydrogen fluoride, sulfur dioxides, nitrogen oxides); carbon monoxide; and organic compounds like benzene, carbon tetrachloride, chlorophenols, trichloroethylene, toluene, xylenes, trichloro-trifluoroethane, polycyclic aromatic hydrocarbons, vinyl chloride, etc. Pathogens can also be found in the solid residues and in the exhaust of poorly designed and badly operated incinerators.[5] In addition, the bottom ash residues are generally contaminated with leachable organic compounds, such as dioxins, and heavy metals and have to be treated as hazardous waste.

The above-mentioned WHO policy was motivated in part by a health risk assessment of small-scale incinerators. The study was commissioned by the World Health Organization and completed in January 2004.[6] The study looked at how small-scale incinerators are operated in the field and their reported emissions of dioxins and furans. Based on this, the study identified three classes: (1) incinerators as “best practice,” operated and maintained properly using sufficient temperatures, afterburners, and other features to limit concentrations of dioxins; (2) incinerators as “expected practice,” that is, improperly designed, constructed, operated and maintained; and (3) “worst-case” incinerators that have no afterburners. The WHO study stipulated three operating scenarios: (1) “low usage” equivalent to 12 kg/month or 1 hour of operation per month; (2) “medium usage” equivalent to 24 kg/week or 2 hours of operation per week; and (3) “high usage” or 24 kg/day or 2 hours of operation per day. The emissions and usage rates were used to estimate uptake rates of dioxins and furans for adults and children via ingestion, and compared them to WHO’s provisional tolerable intake rate (1-4 pg TEQ/kg-day) and an exposure level (0.001 pg TEQ/kg/-day) based on the upper bound of US EPA’s cancer potency factor for dioxins and furans.

The study concluded that ingestion intake rates and carcinogenic risks were unacceptable for the “worst-case” incinerators even at low usage rates. For the “expected usage” incinerators, the low usage rates kept intake below the WHO provisional intake levels but de minimis risks based on US EPA's cancer potency factor were exceeded. Similarly, de minimis cancer risks were exceeded by the "best practice" incinerators at the highest usage.

Health Effects of Incinerator Emissions

Studies investigating the relationship between human exposures to incinerator emissions and the occurrence of health effects in local populations have been difficult, in part because of confounding factors—especially in distinguishing the contribution of incineration versus other pollutant sources—and the complications in measuring highly variable environmental concentrations. In a study of school children living near a wire-reclamation incinerator in Taiwan, Wang *et al*. concluded that the high air pollution levels in the area near the incinerator were associated with a detrimental effect on lung function in the children.[7] Zmirou *et al*. concluded that the purchase of respiratory medication decreased as the distance of residences from incinerators increased.[8] In contrast, Gray *et al*. did not find an adverse effect on the prevalence or severity of childhood asthma among children within a 6-km radius of a sewage sludge incinerator in Sydney, Australia.[9] In a study by Shy *et al*., no difference was found in acute or chronic respiratory symptoms or lung functions between communities adjacent to medical waste and municipal waste incinerators, and comparison groups away from the incinerators.[10] These conflicting results illustrate the complexity of conducting epidemiological studies of the health impacts of incineration in local populations and the need to increase the power of epidemiological studies by looking at multi-site studies.[11]

Despite the uncertainties and at times contradictory results, especially with regards to acute and chronic respiratory disorders, more and more studies in the last two decades indicate a clear association between exposure to incinerator emissions and increased body burdens and adverse health impacts. Various studies in Japan, Spain, and Germany show that incinerator workers or children and other residents living near incinerators have significantly higher blood or urine levels of dioxins, furans, polychlorinated biphenyls, hexachlorobenzene, 2,4/2,5-dichlorophenols, 2,4,5-trichlorophenols, hydroxypyrene, toluene, and tetrachlorophenols compared to control groups or to national averages.[12] Similar studies show a higher prevalence of urinary mutagen and promutagen levels in incinerators workers.[13] Studies in Finland, Germany and the United States show higher levels of mercury in the hair, of cadmium and lead in the blood, of arsenic in urine among incinerator workers or residents living closer to incinerators.[14]

Epidemiological studies indicate an association between incineration and cancer. Studies in the United Kingdom found an increased risk of childhood cancer, childhood leukemia, and solid tumors of all kinds among children living near incinerators.[15] Studies in France, Japan, Italy, United Kingdom, and Sweden found a cluster of soft tissue sarcoma and non-Hodgkin's lymphoma; a two-fold cancer risk; increases in laryngeal cancer; increases in lung cancer or lung cancer mortality; and generally higher risks of all cancers but specifically of stomach, colorectal, liver, and lung cancer among populations living near incinerators.[16] Incinerator workers in Italy, U.S., and Sweden had significantly higher gastric cancer mortality; a high prevalence of hypertention and related proteinuria; and excessive deaths from lung cancer and ischemic heart disease.[17]

Associations have also been found between incineration and reproductive or developmental disorders or genetic anomalies. A study in the U.K. found increased risk of lethal congenital anomalies, in particular, spina bifida and heart defects, with mothers living close to incinerators; and an increased risk of stillbirths and anacephalus among mothers living around crematoria.[18] A study in Belgium found incidences of congenital malformation and a statistically significant increase in multiple pregnancies among residents born in a neighborhood between two incinerators.[19] Another study in the U.K. found an increased frequency of twinning among residents in areas at most risk from incinerator emissions.[20] Children near an incinerator in Germany showed hormonal effects as determined by blood thyroid hormone levels.[21]

Global Trends

In light of the health and environmental impacts of incineration, questions have been raised in recent years regarding the export or use of incinerators especially in developing countries. Some of the problems relate to the siting of incinerators, operator training, and the capacity of developing countries to properly maintain, operate, and test incinerators. The issue is especially problematic with regards to small incinerators. A study of eight medical waste incinerators that were less then two years old was conducted in India. The survey showed problems of smoke emissions, some coming out of the charging doors; large quantities of unburned material in the ash; and lack of operator training.[22] In addition, siting of incinerators was inappropriate in some cases (e.g., located in the children's playground, beside the hospital staff quarters or near a primary school, etc.) and disposal of ash was improper (e.g., ash dumped around trees in the hospital yard). In Kenya, a survey of medical waste incinerators constructed in 2002 revealed that most incinerators were improperly operated, almost all operators had inadequate skills, most of the incinerators had some technical defects, and less than 40% of facility managers were committed to the equipment.[23] A survey of medical waste incinerators built in Tanzania between 2001 and 2003 showed that less than 40% had trained operators, many exhibited smoke problems and problems with ash disposal.[24] To make matters worse, most developing countries cannot test for dioxins and furans, and have little or no capacity to monitor or test for other emissions.

The trend in many industrialized countries is to move away from incineration towards alternative technologies that do not produce any dioxins. In the United States, for example, the number of medical waste incinerators nationwide has dropped dramatically from 6,200 in 1988 to less than a hundred today. Countries like Ireland and Portugal have completely shut down all their incinerators. Canada has effectively phased out incineration in favor of non-incinerator alternatives. Although Germany operates a few large scale incinerators, the country closed down all its on-site hospital incinerators in 2002. Some developing countries have followed suit, such as the Philippines and major cities like New Delhi and Buenos Aires, which have banned or put a moratorium on incinerators. However, the opposite trend is happening in other developing countries in Africa and Asia, with hundreds of incinerators being installed, often with inadequate or no air pollution control. In many cases, these incinerators are brought in through loans or grants from official development aid or international aid agencies.

The WHO policy of 2004 calls for the promotion of non-burn alternatives as a long-term strategy. WHO also recognizes the importance of effective waste reduction and segregation. Any approach to health-care waste must involve both practices and technologies. The Stockholm Convention requires that priority consideration be given to alternative technologies that do not generate dioxins. The Convention also calls for the use of best environmental practices.

Developing a Medical Waste Management System

Details of best environmental practices can be found in the Stockholm Convention's guidance, the Basel Convention's technical guidelines, and other sources.[25] Best environmental practices require the establishment of a health-care waste management system. The institution of a good medical waste management system in a health-care facility requires the following:

- Assessment of the waste stream and existing environmental practices
- Evaluation of waste management options
- Development of plans:
    - Waste management plans
    - Occupational health and safety plans
    - Contingency plans
- Promulgation of institutional policies and guidelines, including roles and responsibilities of personnel
- Allocation of human and financial resources
- Establishment of a waste management organization
- Implementation to plans and actions
- Periodic training
- Monitoring, evaluation and continuous improvement.

On the national level, the following are important:

- Legal framework, including designation of responsible authorities and mechanisms for coordination
- Regulations and guidelines, including clearly defined obligations, system of inspection and enforcement, and penalties
- National strategy or plan of action, including support for regional and local governments
- Capacity building measures
- Allocation of human and financial resources.

A key issue is the need for sufficient financial resources. This would require a budget line item for health-care waste management in national and local health budgets.

Best Environmental Practices

The basic elements of a medical waste management system include the following:[26]

- Waste classification
- Waste segregation
- Waste minimization
- Containerization

- Color coding
- Labeling and signage
- Handling
- Transport
- Storage
- Treatment
- Final disposal of waste.

Health-care waste can be comprised of infectious or biohazardous waste, waste that is hazardous because of its chemical toxicity, radioactive waste, and non-hazardous general (domestic-type) waste. A system of classification should clearly delineate the different types of waste. For example, infectious waste generally includes waste contaminated with blood or body fluids, biological cultures and stocks, and anatomical or pathological waste (body parts, tissues, etc.). Sharps waste (needles, syringes, etc.) are a special category because of both the biological and physical hazard that they pose. Chemical hazardous waste include cytotoxic or chemotherapeutic waste, mercury waste, spent laboratory solvents, cleaners and oils from maintenance, disinfectants, and expired pharmaceutical waste. Tertiary health-care institutions also generate low-level radioactive waste. General domestic waste comprises about 75% of the hospital waste stream, and a significant portion of general waste is recyclable (paper, glass, aluminum, packaging material, etc.) or compostable (hospital kitchen waste, yard waste, etc.).

Segregation is key to efficient health-care waste management. It entails the separation of different types of waste (infectious, sharps, chemically hazardous, radioactive, non-hazardous) at the point of generation, according to the system of handling, treatment and disposal. Some systems, for example, may require separation of anatomical waste from other infectious waste due to differing methods of treatment and disposal. Segregating recyclable waste from other non-hazardous waste allows for waste minimization.

Waste minimization includes inventory control to minimize expired materials, and environmentally preferable purchasing (EPP), that is, the procurement of environmentally sound products. Specifically, EPP means procurement of products that do not contain polyvinyl chloride (PVC), mercury, organophosphate fertilizers, plastics used for delivering fluids into the body that contain di-ethylhexyl-phthalate (DEHP) and other plasticizers that may be linked to birth defects, etc.[27] After a European Parliament resolution in 2001, a U.S. Centers for Disease Control report and a Food and Drug Administration public health notification in 2002, many facilities have moved to reduce or eliminate PVC and DEHP use in health care. Various medical associations have passed resolutions to replace mercury-containing devices in health care with non-mercury substitutes, such as digital, alcohol, galinstan or infrared thermometers; aneroid sphygmomanometers; mercury-free fixatives; etc. Many hospitals in industrialized countries have completed a phase out and have been declared mercury-free facilities. In general, EPP addresses the life cycle of products brought into the facility and takes into account excessive packaging and the toxicity of substances (such as cleaning solvents and disinfectants). Waste minimization also involves recovery, recycling, reuse, and composting in health facilities. Devices to recover formaldehyde or silver from radiology departments are now commercially available. Since infectious and hazardous chemical wastes account for only about 15% of the total waste in health facilities, a program of segregation and recycling can dramatically reduce the amount of waste that requires special treatment.

Other best environmental practices include collection of waste in color-coded containers, use of proper packaging, labeling, and collection of sharps containers and infectious waste bags when 3/4ths full. Designated storage areas should follow WHO recommendations which include limited access. Handling and transport should be done by personnel using appropriate personal protective equipment. Best practices also include the use of environmentally sound treatment technologies.

Alternative Technologies for the Treatment of Medical Waste

The alternative technologies are steam sterilization, advanced steam sterilization, microwave treatment, dry heat sterilization, alkaline hydrolysis, and biological treatment. More detailed descriptions of these alternatives are found elsewhere.[28]

Today, steam sterilization is the most common alternative treatment method. Several types of steam sterilizers or autoclaves are used: gravity-fed, prevacuum, and pulse or multi-vacuum cycle autoclaves. Vacuum systems improve the rate of heat transfer by removing pockets of air that remain inside waste bags thereby enhancing the disinfection process. Compared to incinerators with air pollution control systems such as scrubbers, standard autoclaves of the same throughput capacity have a lower capital cost. Standard autoclaving has the lowest capital costs among alternative technologies. Odors are an issue when using autoclaves in enclosed spaces but proper ventilation and the use of odor removers, such as enzyme-based deodorants, can minimize the problem. With autoclaves, rigorous segregation is important in order to ensure that hazardous chemicals are not included in the waste stream. Some central autoclave plants use detectors for radioactivity, mercury, and volatile organic compounds. Microbial inactivation efficacy testing should also be performed periodically using spore strips or color-changing indicators. Autoclaving would require a post-treatment shredder if the waste is to be rendered unrecognizable and if reduction of waste volume is desired. Advanced single- or multiple-shaft shredders specifically designed for medical waste are capable of reducing waste volume by about 80%. The advanced shredders are typically low-speed/high-torque, single-pass shredders with screened discharge and easily replaceable cutters. Many shredders have ram assemblies to prevent bridging in the feed hopper, auto-reverse features to handle soft waste, and automatic shut-off to limit damage from hard prosthetic metals.

In the last few decades, a second generation of steam-based systems has been developed for the purpose of improving the transfer of heat, achieving more uniform heating of the waste, rendering the waste unrecognizable, and/or making the treatment system a continuous (rather than a batch) process. These advanced autoclaves or advanced steam treatment technologies combine steam treatment with vacuuming, internal mixing or fragmentation, internal shredding, drying, and compaction. Many are designed to remove odors using activated carbon or high efficiency particulate air (HEPA) filters. Often, the resulting waste is not only unrecognizable but also dry and compact, corresponding to as much as 90% volume reduction. Unlike autoclaves, some of these advanced systems have been tested successfully for use with animal waste and could potentially be used with pathological waste including anatomical parts.[29] These advanced steam systems have higher capital costs than standard autoclaves or retorts of the same capacity. Advanced steam systems have some of the same disadvantages as standard autoclaves, such as the need to keep chemicals out of the waste stream.

Microwave treatment is another alternative technology. For years, the most common microwave device has been a medium- to large-scale, semi-continuous system using an internal shredder, rotating auger, and industrial magnetrons. Small batch microwave units are now also available. Microwave units generally have higher capital costs than standard or advanced steam systems. Small desktop technologies that use dry heat are also available for use in medical laboratories, clinics, or in a hospital department. With dry heat, higher exposure time-temperature parameters are usually required compared to those used in moist heat systems in order to meet minimum disinfection levels. Biological systems that are enzyme-based are still in the development stage, however, traditional composting has been used for placenta and other waste. Chemical treatment systems, such as those using lime or peracetic acid, are also available. Some chemical systems may create new problems by producing wastewater containing undesirable byproducts.

Pathological and chemotherapeutic wastes are highly problematic waste streams generated in health care. Alkaline hydrolysis combines steam disinfection with digestion in sodium or potassium hydroxide. These technologies are designed to destroy anatomical parts, organs, tissues, and animal carcasses, breaking down organic material into basic amino acids, sugars, soaps, etc. and leaving behind a calcium bone shadow. In principle, alkaline hydrolysis can also destroy many chemotherapeutic or cytotoxic agents, and aldehydes commonly used in health care, such as formaldehyde and glutaraldehyde. Recent studies have shown that they are also efficacious in destroying prion waste, that is, animal waste containing transmissible spongiform encephalopathies such as “mad cow” disease.[30]

As noted in the introduction, sharps waste poses the greatest risk especially in developing countries. Needle destroyers are now available for use at the point of generation. Some devices utilize electric arcs to melt the needles; others have mechanical cutters to chop the needles or other mechanical means to break and separate the needles from the plastic syringe portion. While there is still some concern regarding possible occupational needle-stick injuries during the process of needle destruction, these devices may be a practical solution to stop the dumping of untreated syringes in open dumpsites in developing countries. Another system involves placing syringes in autoclavable sharps containers, the collection and transport of the containers to a central autoclave plant, steam treatment of the container and sharps, automated dumping of treated sharps in a shredder, and separation of metal and plastic parts using water bins. The stainless steel metals can be recycled in a foundry and the plastics can be sent to a plastic fabricator for reuse as filler. This model system, which has been used in the Himalayan Institute Hospital Trust in India since 1994,[31] offers advantages for low-income countries since it eliminates single-use sharps boxes or containers, which are often expensive or difficult to obtain for poor facilities, and the impact on landfills is removed.

In order to find affordable solutions for developing countries, Health Care Without Harm, with technical support from the World Health Organization, sponsored an international competition in search of innovative treatment technologies for rural areas in developing countries. Contestants from 18 countries submitted designs. Among the winners were: solar-powered autoclaves using solar reflectors or solar collectors, lime treatment and encapsulation, and a small autoclave with internal shredding. Results of the contest are found in www.medwastecontest.org.

The GEF Health-Care Waste Management Demonstration Project [32]

The Global Environmental Facility (GEF), the financing mechanism for the Stockholm Convention, has approved a health-care waste management global demonstration project. The project involves the United Nations Development Programme, World Health Organization, Health Care Without Harm, and governmental and non-governmental organizations in eight countries (Argentina, India, Latvia, Lebanon, Philippines, Senegal, Tanzania, and Vietnam). Best environmental practices and technologies will be demonstrated through the development of model facilities and programs, building institutional capacity including management systems, deployment of alternative technologies, awareness-raising, training and education on the local and national levels, and activities to promote sustainability, replicability, and information dissemination on the national, regional, and global levels. In addition to demonstrating waste minimization, pollution prevention, segregation, and other environmental practices, the project will utilize autoclaves, advanced steam technologies including mobile treatment systems, microwave treatment, alkaline hydrolysis, and use of mercury-free alternatives. A city-wide sharps treatment system using reusable (autoclavable) sharps containers, collection, transport, centralized autoclave treatment, separation, and recycling of metal and plastic parts will be demonstrated. Low-cost, locally manufactured, appropriate technologies for rural areas will be developed and demonstrated in Tanzania using the results of the international competition. The objective of the project is to demonstrate and promote best practices and technologies for health-care waste management in order to reduce health-care waste and virtually eliminate environmental releases of dioxins and mercury from health care. The Global Environmental Facility demonstration project will be a valuable tool for raising awareness and disseminating information on environmentally sound health-care waste management.

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REFERENCES:

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[1] A. Kane, J. Lloyd, M. Zaffran, L. Simonsen, and M. Kane, *Bull. World Health Org.*, 41: 151-154, 1999.
[2] "Review of Impacts from Microbiological Hazards in Health-Care Wastes," Department of Blood Safety and Clinical Technology, and Department of Protection of the Human Environment, World Health Organization, Geneva, 2004.
[3] "Smallpox: Russian Children Afflicted by Dumped Vaccines," Reuters Online, 19 June 2000.
[4] "Safe health-care waste management," policy paper, World Health Organization, Geneva, August 2004.
[5] M. Barbeito and M. Shapiro, "Microbiological Safety Evaluation of a Solid and Liquid Pathological Incinerator," *J. Medical Primatology*, 6:264-273, 1977; S. Klafka and M. Tierney, "Pathogen Survival at Hospital/Infectious Waste Incinerators," *Proceedings: National Workshops on Hospital Waste Incineration and Hospital Sterilization*, EPA Office of Air Quality Planning and Standards, EPA-450/4-89-002, January 1989; *Hospital Medical Waste Incinerator Operation and Maintenance*, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, March 1989.
[6] "Assessment of Small-Scale Incinerators for Health Care Waste," S. Batterman, report prepared for the Protection of the Human Environment, World Health Organization, Geneva, January 21, 2004.
[7] J.Y. Wang, T.R. Hsiue, and H.I. Chen, *Arch. Dis. Child. 67*(4): 488-490, 1992.
[8] D. Zmirou, B. Parent, and J.-L. Potelon, *Rev. Epidem. Sante Publ. 32*:391-397, 1984.

[9] E.J. Gray, J.K. Peat, C.M. Mellis, J. Harrington, and A.J. Woolcock, *Aust. New Zealand J. Medicine 24*(2): 168-175, 1994.
[10] C.M. Shy *et al., Environmental Health Perspectives 103*(7-8): 714-724, 1995.
[11] *Waste Incineration and Public Health*, Committee on Health Effects of Waste Incineration, National Research Council, Washington, D.C.: National Academy Press, 2000.
[12] S. Kumagai and S. Koda, J. Occupational Environmental Hygiene, 2(2): 120—125, (February 2005); S. Kumagai, S. Koda, T. Miyakita and M. Ueno, Occupational Environmental Medicine 59: 362-368 (2002); K. Kitamura, Y. Kikuchi, S. Watanabe, G. Waechter, H. Sakurai, and T. Takada, Journal Epidemiology 10(4): 262-270 (2000); C. Gonzalez, M. Kogevinas, E. Gadea, A. Hulci, A. Bosch, M. Bleda, and O. Papke, Arch. Environ. Health 55: 259-267 (2000); A. Schecter, H. Miyata, S. Ahta, O. Aozasa, T. Nakao, and Y. Masuda, Organohalogen Compounds 44: 247-250 (1999); H. Miyata, S. Kuriyama, T. Nakao, O. Aozasa, and S. Ohta, Organohalogen Compounds 38: 143-146 (1998); B. Holdke, W. Karmaus and H. Kruse, Die Gesundheitswesen 60 (8-9): 505-512 (1998); A. Schecter et al., *Occup. Environ. Medicine, 52*, 385-387 (1995); R. Wrbitzky et al., *Int. Arch. Occup. Environ. Health, 68,* 13-21 (1995); J. Angerer et al., Int. Arch. Occup. Environ. Health, 64, 266-273 (1992); A.J. Schecter, R. Malkin, O. Papke, M. Ball, and P.W. Brandt-Raul, *Med. Sci. Res. 19*: 331-332 (1991);.
[13] X.F. Ma et al., *J. Toxicol. Environ. Health*, 37, 483-494 (1992); J.M. Scarlett et al., *J. Toxicol. Environ. Health, 31*, 11-27 (1990).
[14] P. Kurttio et al., *Arch. Environ. Health, 48*, 243-245 (1998); R. Wrbitzky et al., *Int. Arch. Occup. Environ. Health*, *68*, 13-21 (1995); R. Malkin et al., *Environ. Res.*, *59*, 265-270 (1992).
[15] E. Knox, *International Journal of Epidemiology*, 29:391-397 (2000); E.G. Knox and E.A. Gilman, *J. Epidemiol. Community Health 52*: 716-726 (1998).
[16] J.-F. Viel, P. Arneux, J. Baverel and J.-Y. Cahn, *Am. J. Epidem. 152*: 13-19 (2000); H. Miyata, S. Kuriyama, T. Nakao, O. Aozasa, and S. Ohta, *Organohalogen Compounds 38*: 143-146 (1998); P. Michelozzi et al., *Occup. Environ. Med.*, *55*, 611-615 (1998); A. Biggeri et al. *Environ. Health Perspect.*, *104*, 750-754 (1996); P. Elliott et al., Br. J. Cancer, 73, 702-710 (1996); P.J. Diggle, *J. R. Stat. Soc. A 153*: 349-362 (1990); P. Gustavsson, *Am. J. Ind. Medicine, 15*, 129-137 (1989).
[17] E. Rapiti et al., *Am. J. Ind. Medicine, 31*, 659-661 (1997); E.A. Bresnitz et al., Am. J. Ind. Medicine, 22, 363-378 (1992); P. Gustavsson, Am. J. Ind. Medicine, 15, 129-137 (1989).
[18] T. Drummer, H. Dickinson and L. Parker, *J. Epidemiological Community Health*, 57, 456-461 (2003).
[19] N. Van Larebeke, proceedings of the seminar "Health Impacts of Waste Management Policies," Hippocrates Foundation, Kos, Greece, 12-14 November 1998.
[20] O.L. Lloyd et al., *Br. J. Ind. Medicine*, *45*, 556-560 (1988).
[21] N. Osius and W. Karmaus, *Die Gesundheitswesen 60*: 107-112 (1998).
[22] J. Emmanuel, G. McRae, and F. Mahmoudi, "Environmentally Responsible Management of Health Care Waste With a Focus on Immunization Waste," working draft, Health Care Without Harm, Washington, DC, October 2002; also presented at the Safe Injection Global Network and National AIDS Control Programme Managers in Africa conference, Nairobi, Kenya, September 18-20, 2003.
[23] E. Taylor, "Rapid Assessment of Small-scale Incinerators," Final Draft, Kenya, July 2003.
[24] Sawadago Adama, "Waste management assessments conducted in Africa in 2003," presentation at the Safe Injection Global Network and National AIDS Control Programme Managers in Africa conference, Nairobi, Kenya, September 18-20, 2003.
[25] "Guidelines on best available techniques and provisional guidance on best environmental practices relevant to Article 5 and Annex C of the Stockholm Convention on Persistent Organic Pollutants," Revised Draft, United Nations Environment Programme, Geneva, Switzerland, December 2006 (approved May 2007); "Technical Guidelines on the Environmentally Sound Management of Biomedical and Health-Care Waste," Basel Convention Secretariat, Basel Convention on the Control of Transboundary Movements of Hazardous Waste and their Disposal," UNEP, Geneva, Switzerland, 2002; K.D. Wagner, C.D. Rounds, and R.A. Spurgin, Editors. *Environmental Management in Healthcare Facilities*, Philadelphia, PA: W.B. Saunders Company, 1998; C.L. Bisson, G. McRae, and H.G. Shaner. *An Ounce of Prevention: Waste Reduction Strategies for Health Care Facilities*, Chicago, IL: American Society for Healthcare Environmental Services, 1993; other resources available at the Health Care Without Harm website www.noharm.org.
[26] A. Prüss, E. Giroult, and P. Rushbrook , *Safe management of wastes from health-care activities*, Geneva: World Health Organization, 1999.
[27] See for example Health Care Without Harm and CleanMed websites: www.noharm.org, www.cleanmed.org
[28] J. Emmanuel, *Non-Incineration Medical Waste Treatment Technologies*, Washington, DC: Health Care Without Harm, August 2001.

[29] "Treatment and Destruction of Pathological Waste in a Large Rotating Autoclave," L.J. Thompson and I.F. Salkin, presented at the American Biological Safety Association Annual Meeting, 1999.

[30] European Commission Regulation (EC) No 92/2005, January 19, 2005; J. Emmanuel, J. Keene and R. Trower, "Evaluation of Alkaline Hydrolysis Digestion Technology for Decontamination and Disposal of Potentially Infectious Animal Carcasses," Division of Environmental Protection, National Institutes of Health, Bethesda, Maryland, January 18, 2005.

[31] J. Emmanuel and P. Saoke, "Alternative Waste Treatment Technologies," in the Report of the Pre-ICASA Conference Satellite Meeting, Safe Injection Global Network and National AIDS Control Programme Managers in Africa (World Health Organization), Nairobi, Kenya, 18-20 September 2003.

[32] J. Emmanuel, G. McRae, J. Weinberg, and F. Mahmoudi, "Promoting Best Practices to Reduce Health Care Waste and Avoid Dioxin and Mercury Releases," GEF Concept Paper, Health Care Without Harm, Washington, D.C., September 2003.