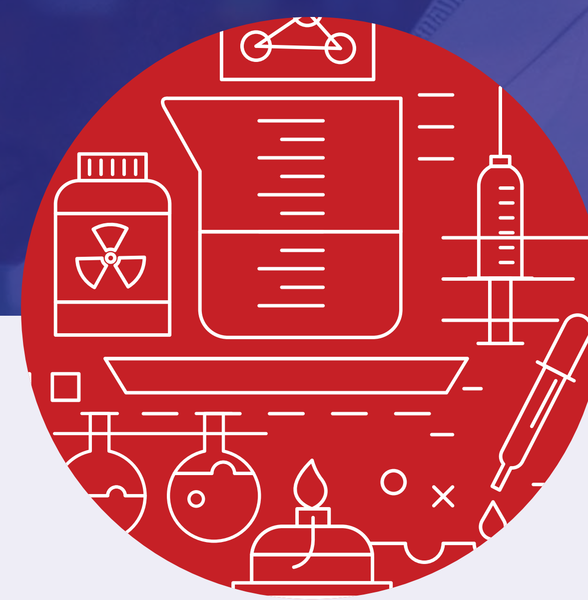
Framework for the Selection, Implementation, and Financing of Strategies for the Management and Treatment of Laboratory Waste

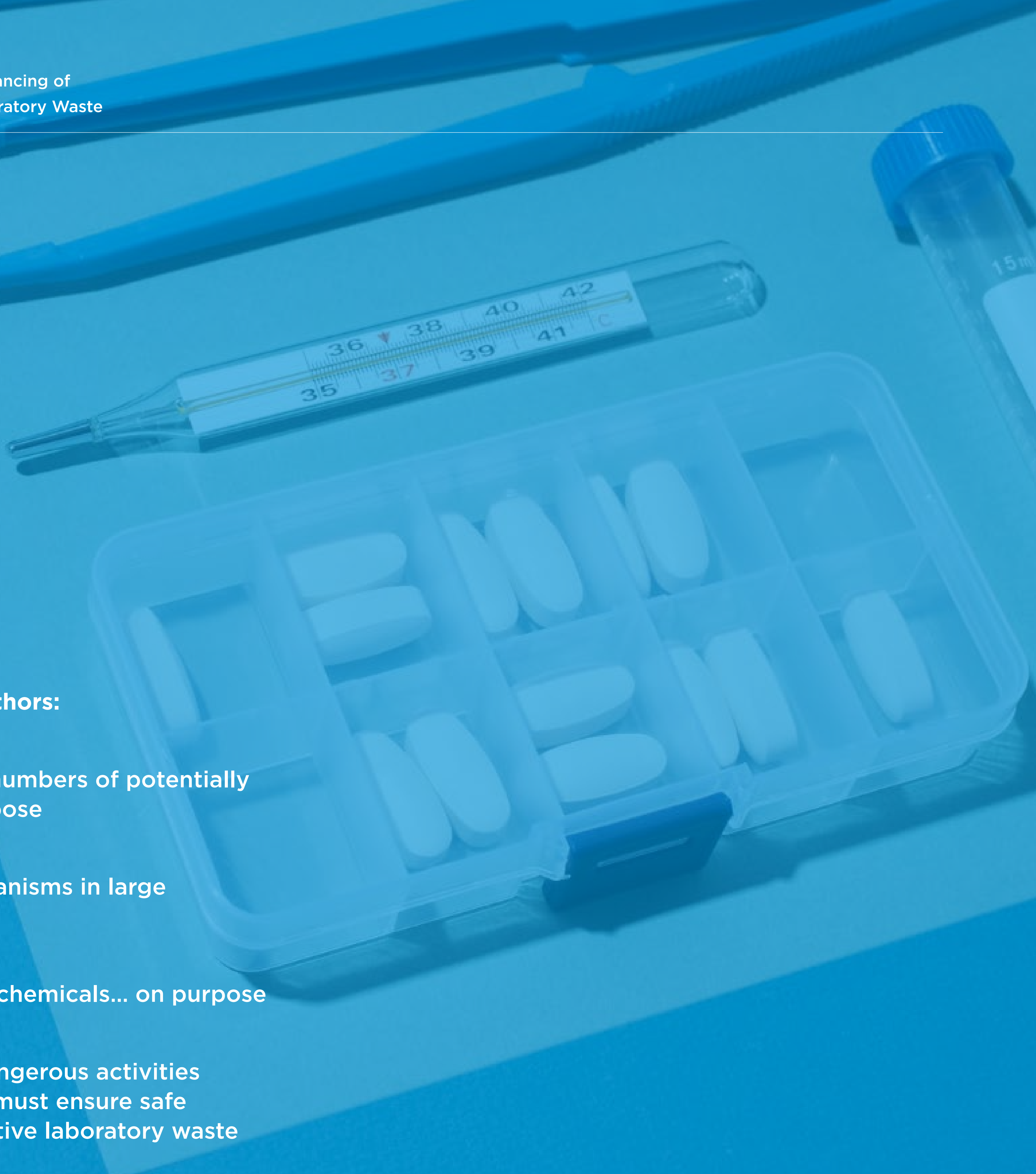
February 2026



PEPFAR
U.S. President's Emergency Plan for AIDS Relief

Lab CoP
ASLM

ASLM
AFRICAN SOCIETY FOR LABORATORY MEDICINE



Some thoughts from the Authors:

Laboratories manage large numbers of potentially dangerous samples...on purpose

Laboratories grow microorganisms in large quantities ...on purpose

Laboratories use hazardous chemicals... on purpose

With so many potentially dangerous activities being done on purpose, we must ensure safe work environment and effective laboratory waste management.

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Preface

Rapid advancements in laboratory medicine have brought significant benefits to the African continent. These developments have also led to an exponential increase in the amount and complexity of laboratory waste generated. With the evolution of medical technologies and the development of diagnostic capabilities, laboratories now use a wide range of chemicals, reagents, and sophisticated equipment. This has resulted in a more varied spectrum of waste types, including hazardous chemicals, biological materials, and electronic waste, each of which requires specific disposal techniques to manage effectively.

The increase in waste production has highlighted the critical need for robust waste treatment systems. Effective waste treatment is imperative for compliance with environmental and health regulations and reducing the risk of contamination and pollution. Such risks pose significant threats to the environment and public health, particularly through increased exposure to hazardous substances. Moreover, the types of waste generated in modern laboratories often contain valuable materials that could be recovered and recycled, thereby promoting sustainability. Implementing effective waste treatment systems also requires constant improvements in the sorting, recycling, and safe disposal of laboratory waste.

Additionally, many but not all African countries are signatories to international regulations and conventions that govern environmental protection and waste management. Key frameworks include the Basel[1] , Stockholm[2] , Rotterdam[3] , and Bamako Conventions[4]. These conventions provide for measures to reduce the production of hazardous waste, to ensure its proper treatment and disposal, and to engage in international cooperation to improve waste management practices worldwide.

This document is designed to provide stakeholders in African countries with essential information, guidance, and tools for establishing, implementing, financing, and maintaining effective laboratory waste management practices. It presents detailed recommendations, strategies and guidance for the selection, and implementation of safe and sustainable waste treatment strategies.

This document is designed for periodic review and updates, including amendments, improvements, and omissions, to ensure that it remains a current and relevant resource within national and regional systems.

1 Basel Convention - The provisions of the Convention relate to the reduction of hazardous waste generation and the promotion of the environmentally sound management of hazardous wastes, the restriction of transboundary movements of hazardous wastes, and the application of a regulatory system for authorized movements of hazardous waste.

2 The Stockholm Convention on Persistent Organic Pollutants is a global treaty designed to protect human health and the environment from chemicals that remain intact in the environment for long periods, are widely distributed geographically, accumulate in the fatty tissue of humans and wildlife, and have harmful impacts on human health or the environment.

3 Rotterdam Convention - It aims to promote shared responsibility and cooperation between Parties in addressing the international trade of certain hazardous chemicals. The agreement establishes a Prior Informed Consent (PIC) procedure for the import of hazardous chemicals, ensuring that potential harm is minimized over time.

4 The Bamako Convention is a treaty of African nations prohibiting the import of all hazardous waste (including radioactive)

Acknowledgements

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The development of this document was made possible thanks to the support of the US Centers for Disease Control and Prevention (CDC). The African Society for Laboratory Medicine (ASLM) coordinated this effort, in close collaboration with Waste Not Want Not (WNWN) and a Technical Working Group (TWG) of regional experts. This collaborative approach has been instrumental in developing a systematic guide for the selection and implementation for clinical laboratory waste treatment methods in the African region, thanks to the invaluable support and expertise provided by these stakeholders.

This collaborative effort underscores the importance of ongoing partnerships and support in advancing effective waste management practices.

We wish to express our gratitude to all national, regional and international stakeholders, who provided essential information, data, knowledge and expertise, enabling us to complete this document.

ASLM and WNWN International, Inc.

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List of Acronyms

ASLM	African Society of Laboratory Medicine
AMREF	African Medical and Research Foundation
BSL	Biosafety Level
DBS	Dried Blood Spot
CDC	Centers for Disease Control and Prevention
COE	Center of Excellence
CSR	Corporate Social Responsibility
CSSD	Central Sterilization Supply Department
DGHT	Division of Global HIV and TB
ECHA	European Chemicals Agency
EID	Early Infant Diagnosis
FFP	Filter Face Piece
GEF	The Global Environment Facility
GTC	Guanidinium thiocyanate
HCW	Healthcare Waste
HCWM	Healthcare Waste Management
HIV	Human Immunodeficiency Virus
HVAC	Heating Ventilation Air Conditioning
ICRC	International Committee of the Red Cross
ICU	Intensive Care Unit
ISO	International Standard Organization

ISWA	International Solid Waste Association
LWM	Laboratory Waste Management
NIOSH	National Institute Occupational Safety and Health
MSF	Medicines Sans Frontiers (Doctors Without Borders)
OHS	Occupational Health and Safety
PEPFAR	President's Emergency Plan for AIDS Relief
PPE	Personal Protection Equipment
PPP	Public Private Partnership
PVC	Poly Vinyl Chloride
SOPs	Standard Operating Procedures
STAATT	State And Territorial Association Alternative on Treatment Technologies
UN	United Nations
UN GEF	United Nations Global Environmental Facility
UNAIDS	The Joint United Nations Program on HIV/AIDS
UNDP	United Nations Development Program
UNEP	United Nations Environmental Program
UNICEF	United Nations Children's Fund
VL	Viral Load
VL/EID	Viral Load / Early Infant Diagnosis
WASH	Water Sanitation and Hygiene
WHO	World Health Organization
WEEE	Waste from Electric and Electronic Equipment

Definitions

Anatomical Waste / Pathological Waste:
This waste stream consists of tissues, organs, body parts, blood, and body fluids from patients, human fetuses, and animal carcasses excluding teeth and hair.

Chemical Waste:
This waste stream consists of discarded solid, semisolid, liquid, and gaseous products containing identifiable chemicals, such as diagnostic and experimental work and chemicals used for cleaning, housekeeping, and decontamination or disinfecting procedures. Chemical waste from healthcare may be considered hazardous or non-hazardous, depending on the chemical's product or device and how medical professionals use it.

Cleaning:
Regular or interventional physical removal of natural and incidental contamination of the existing workplaces, furniture, facilities, or rooms.

Clinical Staff:
All staff involved in observing and treating actual patients rather than theoretical or laboratory studies. Examples: Nurses, Doctors, Physicians, Dentists, Radiologists, support staff, etc.

Color-coding system:
A system for identifying and relating the hazards and contents of waste packaging/containers using different colors.

Contamination:
Direct or potential contact with a contaminant. Examples: Blood or body fluids, pollutants, radioactive material, chemicals, etc.

Decontamination:
Physical or chemical process intended to reduce or inactivate the contamination to a safe or acceptable level.

Non-hazardous or general healthcare waste:
General waste streams such as plastic, paper, glass, and cardboard that do not pose a biological/chemical/radiological hazard to human health or the environment.

Genotoxic:
Refers to properties capable of interacting directly with genetic material, causing damage to the DNA to be assayed. The term may refer to carcinogenic, mutagenic, or teratogenic properties.

Hazard:
The ability of any agent, equipment, material, or process to cause harm.

Hazardous Waste:
Waste that may pose physical, chemical, microbiological, or radioactive risks to human health, including a significant adverse effect on public health and the environment.

Healthcare Waste:
All waste generated from the provision of healthcare activities and services in any healthcare establishments, research facilities, and laboratories that could pose a risk to the health of healthcare workers, the public, or the environment. Note that some countries use the term "Medical Waste" or "Biomedical Waste."

Infectious Waste:
Waste has been in contact with human blood or bodily fluid and is likely to spread disease. For example, gauze, cotton, dressings, microbiological waste, IV fluid lines, blood bags, gloves, anatomical waste, and surgical instruments.

Laboratory Waste:
Health risk waste originating specifically from a laboratory

environment, which includes all streams of different forms and quantities depending on the activities and high volumes of the special waste category: Solvent waste, GTC waste, and Microbiological Waste. (See definition below).

Microbiological waste:
This includes cultures and stocks of infectious agents and other specimens generated in diagnostic or pathology laboratories. This category of waste includes culture dishes (plates), and other growth media and devices used for transfer, inoculation, and mixing. It also includes discarded live and attenuated vaccines.

Mixed Waste:
Waste with multiple hazardous substances such as chemical waste and either infectious agents or hazardous cytotoxic substances or both.

Packaging:
Often used interchangeably with the word ‘containerization.’ This refers to the materials used to wrap and safely contain the relevant waste streams to prevent exposure during transport to final disposal. Examples: Rigid plastic containers, flexible plastic bags, lined fiberboard box sets, etc.

Personal Protective Equipment:
Specialized clothing or equipment worn by employees for protection against a hazard.

Sharps Waste:
Waste that may puncture the skin and cause disease. Examples: Needles, infusion sets, scalpels, knives, blades, lancets, and broken glass.

Sodium Hypochlorite Solution (Bleach):
Widely used for decontamination of surgical instruments, laboratory equipment, and spot disinfection of counters and floors in healthcare facilities. Example: JIK is a local brand of sodium hypochlorite available in many parts of Africa.

Special Waste:
Comprises hazardous and non-hazardous waste that has physical or chemical characteristics that are different from healthcare waste and require special packaging and handling. Examples: Lead, batteries, pressurized containers, and electrical and electronic waste.

Waste treatment technology:
A wide range of processes and methods used to effectively treat and manage various waste materials. It includes physical, chemical, and biological treatment methods aimed at reducing the volume and toxicity of waste and recovering valuable resources from it.

1. Introduction

The advent of sophisticated laboratory techniques has brought a paradigm shift in the field of healthcare, with profound implications for the African continent. These invocations have enhanced the precision of diagnostic procedures and the efficacy of patient treatment, underscoring the pivotal role of laboratory medicine in modern healthcare systems. However, these developments have also introduced considerable challenges in the management and treatment of an increased volume and complexity of laboratory waste. As medical technologies evolve and diagnostic capabilities expand, laboratories are using an increasingly diverse range of chemicals, reagents, and sophisticated equipment. This has resulted in the generation of a broader spectrum of waste types, including hazardous chemicals, infectious materials, and electronic waste. The management and disposal of these materials often necessitates specific processes, such as chemical neutralization or specialized recycling processes, which may not be readily available or economically feasible in many African settings. Moreover, the expansion of diagnostic capabilities has resulted in laboratories generating increased quantities of infectious waste, which poses specific health risks. This type of waste necessitates rigorous biosafety and biosecurity measures to prevent the transmission of infectious agents. However, the infrastructure for safe disposal such as autoclaves and secure incineration facilities is not readily available in many facilities.

The management of clinical laboratory waste management in Africa is confronted with several challenges, including the lack of specialized facilities and technology dedicated to the treatment of such waste. The traditional waste treatment systems that are often under-resourced and lacking in technical sophistication are ill equipped to manage the scale and diversity of modern laboratory waste. This frequently results in improper disposal methods, such as open burning or dumping in unauthorized areas, which pose serious environmental and health risks.

Furthermore, the absence of stringent regulatory enforcement and guidelines means that even when protocols exist, they are often not adhered to. This situation is further exacerbated by a shortage of trained personnel who possess the requisite knowledge to manage waste effectively. As a result, hazardous materials, including infectious agents and chemical contaminants, frequently enter the environment, affecting both public and environmental health.

The complexity of these challenges underscores the necessity for a strategic approach at the national level to develop effective waste treatment systems that can provide sustainable support for these advancements. In the absence of a concerted effort to upgrade and expand waste management infrastructure, in which treatment plays a leading role, along with clear regulatory frameworks and consistent enforcement, the health and environmental risks associated with laboratory waste will continue to grow. This underscores the necessity for integrated waste management strategies that encompass not only the safe disposal of hazardous materials but also the training of personnel and the establishment of national standards to guide laboratory waste management and disposal practices across Africa.

2. Background

The necessity of efficacious laboratory waste management and treatment systems has been accentuated by high-profile disease outbreaks, including Ebola, Zika, and the ongoing pandemic of COVID-19 over the past decade. These outbreaks have demonstrated the vital importance of biosafety, biosecurity, and the safe handling of potentially infectious waste. If mismanaged, such waste can significantly contribute to the spread of diseases. In response, there has been a global initiative to establish more rigorous protocols and regulations on waste management and treatment. Training and capacity-building initiatives have been enhanced to ensure that personnel are well equipped to manage hazardous waste safely.

Historically, interventions aimed at strengthening laboratory waste management in the African region have primarily focused on the initial stages of waste segregation, handling, and disposal within laboratory facilities. The promotion of Quality Management Systems in African laboratories has been a crucial driver in enhancing these practices at the facility level, guaranteeing conformity with any existing national, regional, or international standards. Nevertheless, even at the facility level, numerous challenges persist due to inadequate infrastructure and resources, which significantly impedes the establishment and implementation of effective waste management processes.
The custody and disposal of laboratory waste outside of the laboratory facility present several challenges, particularly given that such waste often enters fragmented national waste management systems that are ill equipped to manage hazardous materials safely. The transition from a controlled laboratory environment to a less regulated external environment significantly elevates the risk associated with the transport and disposal of such waste. Furthermore, the involvement of third-party waste handlers, who may not consistently adhere to the required safety standards, serves to compound these risks.

The lack of a robust regulatory framework and inadequate regulatory oversight in many African countries also contribute to the shortcomings in national waste treatment systems. Furthermore, the lack of implementation of national policies on hazardous waste serves to complicate further the establishment of standardized procedures for the safe and efficient management of such materials. Additionally, there is also a notable deficit in knowledge among third-party waste handlers regarding the specific nature of the waste they deal with and the proper methods for its safe handling and disposal. This lack of expertise is further compounded by the lack of, or inconsistent application of handling, transportation, and treatment protocols, which result in unsafe practices that pose significant risks to public health. For example, improper segregation and disposal of Infectious waste can result in the spread of infectious diseases, while mishandling chemical waste can lead to toxic exposures. Inadequate laboratory waste storage, transportation and treatment procedures can also cause significant environmental contamination, with adverse effects on water sources and soil quality. This in turn, has implications for public health through the food chain and drinking water1. These challenges underscore the urgent need for comprehensive guidance, training, and capacity building for both policymakers and waste handlers.

These challenges highlight the critical need to strengthen national-level laboratory waste management and treatment systems in African countries. It is essential that a comprehensive strategy be implemented. This will unify the management efforts of individual laboratory facilities with broader national handling and treatment processes. Such an approach would not only ensure adherence to international safety standards but would also promote uniformity and compliance across all stages of waste management. By strengthening national frameworks and infrastructure, and by fostering an integrated approach to waste management, African countries can enhance public health outcomes, protect the environment, and align with international safety standards, thereby supporting sustainable development and safety in laboratory practices across the continent.
This document is the culmination of extensive work conducted by

ASLM and its partners across several countries with the objective of strengthening laboratory waste management for HIV viral load (VL) and early infant diagnosis (EID) diagnostic processes. Through this work, ASLM has identified significant deficiencies in the selection and implementation of effective and sustainable waste handling and treatment technologies. Additionally, the work highlights the critical gaps in the development of sustainable financing models to ensure the ongoing operation and maintenance of these technologies, which is crucial for long-term efficacy and sustainability.

This document provides comprehensive guidance for the selection, implementation, and financing of clinical laboratory waste treatment strategies across all health laboratories in Africa. It addresses the critical necessity for effective waste management to ensure public health, environmental safety, and regulatory compliance. In addition, the document provides an overview of the current state of waste management identifying key stakeholders such as government agencies, international organizations, healthcare providers, and private sector partners and details relevant national and international regulations. It highlights gaps in knowledge, technology, and financing, establishing criteria for selecting suitable waste treatment technologies and providing operational guidance for their implementation. The document emphasizes the importance of training, capacity building, and sustainable financing models. It also delineates the roles and responsibilities of various stakeholders, presents case studies of successful implementations, and provides guidance for monitoring, evaluation, and continuous improvement. This comprehensive approach aims to enhance laboratory waste management practices, ensuring long-term efficacy and safety across Africa.

The African Society for Laboratory Medicine (ASLM) is a Pan-African professional body whose mission is to advocate for the essential role and needs of laboratory medicine across the African continent. ASLM serves the community of laboratory professionals and networks of public health laboratories in Africa, supporting the global health agenda for the laboratory sector through collaboration with the Africa Centers for Disease Control and Prevention (CDC) and the World Health Organization (WHO) Regional Offices for Africa and the Eastern Mediterranean. The primary goal of ASLM is to promote the value of all medical laboratories and laboratory networks in Africa. By coordinating and synergizing partnerships and advocating for cost-effective interventions for laboratory strengthening, ASLM aims to enhance laboratory capacity on the continent. Since its inception, ASLM has collaborated with a range of stakeholders including governments, local and international organizations, implementing partners, and the private sector to advance medical laboratory capacity and support the implementation of core capacities relevant to the International Health Regulations (IHR) and Universal Health Coverage (UHC).

To facilitate the aforementioned critical functions, ASLM has formed collaborative partnership with the U.S. CDC, specifically the Division of Global HIV and TB, under the auspices of the President's Emergency Plan for AIDS Relief (PEPFAR). The objective of this collaboration is to strengthen laboratory systems for HIV VL and EID, with a view to enhance the quality of care for people living with HIV (PLHIV) and tuberculosis (TB). By collaborating with government entities, local and international organizations, implementing partners, and the private sector, ASLM and the U.S. CDC are strengthening diagnostic and healthcare services throughout the continent. This partnership focuses on capacity building, the implementation of advanced diagnostic technologies, quality assurance, and the development of sustainable health systems to effectively manage and control HIV and TB in Africa. Capacity building in laboratory waste management is a process and a commitment to promoting a culture of safety, sustainability, and compliance. When upheld, this commitment benefits the organization, its employees, and the wider community, ensuring a safer and more sustainable environment for all.

Capacity building can facilitate the transfer of knowledge through competency-based initiatives, enabling the sharing of best practices and lessons learned. This enhances collaboration and partnership, ultimately leading to effective outcomes in addressing specific issues. Over the years, ASLM has been instrumental in promoting and leading numerous initiatives aimed at enhancing laboratory capacity across the African continent:

A case study on the management of guanidine thiocyanate waste generated from HIV VL testing.

One area of particular importance for this collaboration is the management and treatment of laboratory waste generated by HIV diagnostic processes in Africa. For example, a considerable number of PCR diagnostic platforms utilize reagents containing Guanidinium thiocyanate (GTC) a potentially toxic chemical if mixed with acid-based substances, for the lysis of viral particles generated in the context of HIV VL/EID and TB testing processes. Additionally, GTC can also be found within the liquid waste contained in some Point- of- Care (POC) testing cartridges. Considering the growing intricacy and quantity of waste generated by laboratories in Africa, ASLM is facilitating the development of comprehensive guidance and protocols to address the challenges associated with the treatment of these waste streams. This initiative aims to ensure the secure and effective disposal of hazardous materials, reduce environmental impact, and safeguard public health. By collaborating with various stakeholders, including government agencies, local and international organizations, and private sector partners, ASLM strives to implement best practices for waste management and treatment across the continent.

See: https://aslm.org/resource-centre/?projects=&resource_type=&topics=waste-management

RATIONALE AND COVERAGE

This document has been developed to offer practical guidance and recommendations based on international practices and experiences in laboratory waste management. It is important to note that this document designed to support and inform, is not intended to supersede any relevant national legislation on healthcare and laboratory waste management. Instead, this guidance aims to complement existing regulations by serving as a reference point for implementing effective waste management practices and integrating various mitigation measures including technical, administrative, practical, and occupational health and safety (OHS) measures across the diverse settings of African countries and their laboratory systems.

This document is aligned with the One Health approach (Figure 1), as it addresses the management of hazardous waste in human medical laboratories, which is also applicable to similar waste streams that are generated in the veterinary and environmental laboratories.

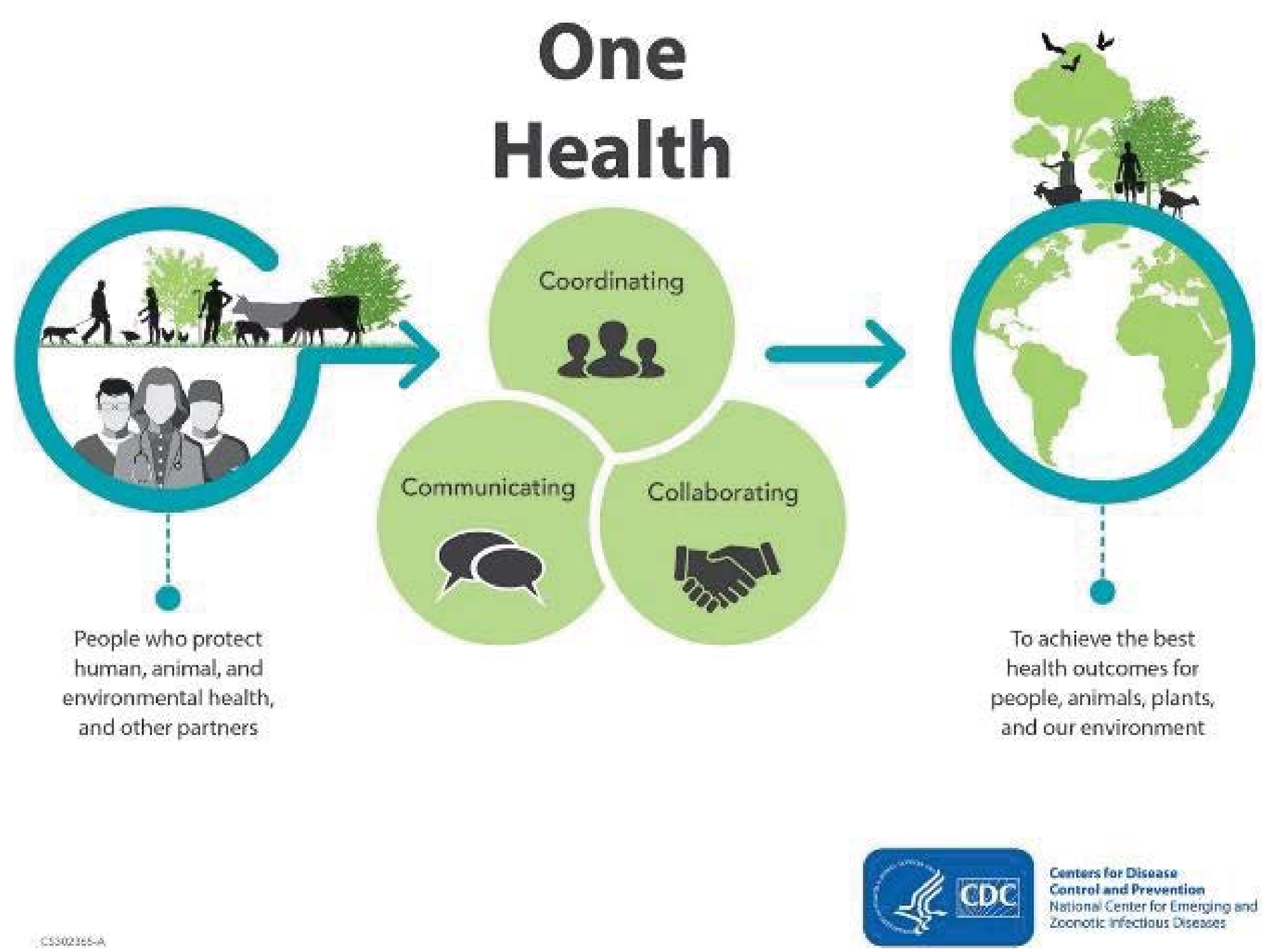


Image link: https://www.cdc.gov/one-health/php/communications-resources/index.html

Figure 1 THE ONE HEALTH APPROACH

The guideline is designed for implementation in the following types of laboratories and for the management of the waste generated from their processes:

a) **Blood banking and Serology (Immunohematology, Transfusion Medicine):** These facilities manage blood products and perform serological testing, necessitating stringent waste handling to prevent biohazard risks.

b) **Chemistry:** Laboratories that work with a variety of chemicals need robust procedures to manage chemical waste safely.

c) **Hematology:** These laboratories deal with blood and its components, and the disposal of sharps and biological waste is critical.

d) **Histopathology and cytopathology:** Laboratories that examine tissue samples to diagnose diseases must carefully manage biological and chemical waste to avoid contamination.

e) **Microbiology:** Handling of microbial cultures and infectious agents in these laboratories requires specific protocols to mitigate biohazard risks.

f) **Microscopy:** Although these laboratories often handle less biohazardous materials, they must still follow best practices for the disposal of used slides and other materials.

g) **Molecular biology:** These facilities handle genetic material and often use reactive chemicals that require careful disposal.

h) **Public health:** Laboratories conducting water and food quality testing, environmental substance testing, and other public health-related analyses must responsibly manage a variety of hazardous and non-hazardous wastes.

This document was developed for the following purposes:

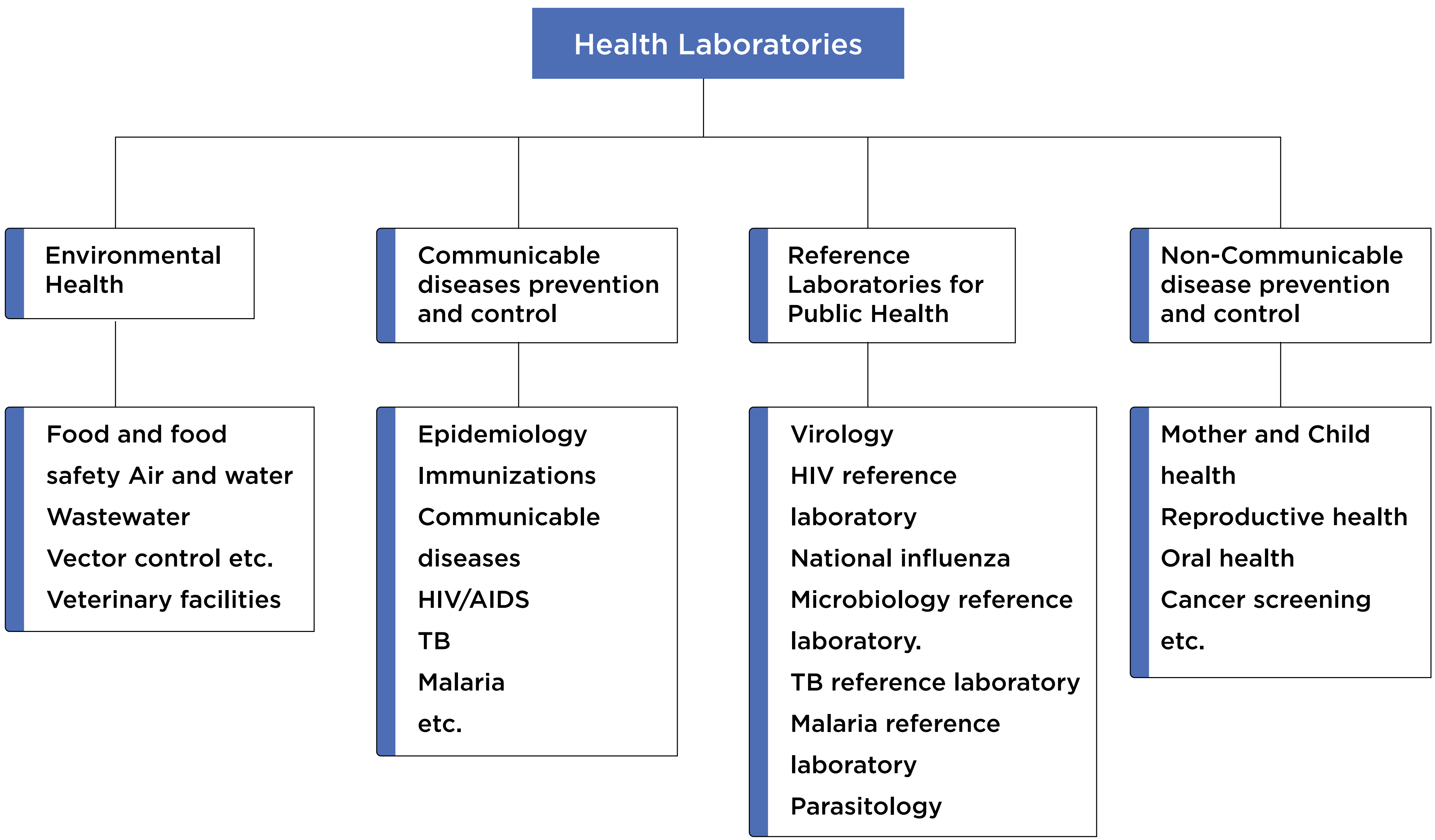
- provide clear, practical advice tailored to the diverse and sophisticated waste streams now common in African laboratory settings.
- provide strategies for overcoming infrastructure deficits by outlining sustainable waste management practices that can be adopted in resource-limited settings.
- provide guidance on establishing robust biosecurity measures and waste handling protocols to mitigate risks and ensure that infectious agents are safely contained and disposed.
- provide strategies to standardize waste management practices across the continent, ensuring consistent adherence to safety and environmental standards.
- assist policy makers and regulatory bodies in establishing clear, enforceable standards and regulations for laboratory waste management. By providing a detailed framework for action, the document will help to ensure that laboratory waste is managed in a safe, compliant, and environmentally responsible manner.
- enhance awareness, education, and capacity building on best practices for laboratory waste management, and foster collaboration among laboratories, government bodies, and international organizations

This document is intended for a wide audience involved in the management and treatment of clinical laboratory waste in Africa. It is intended for healthcare providers and professionals working in a wide range of healthcare laboratories (Figure 2), including those specializing in HIV VL and EID diagnostic processes.

Government agencies responsible for health regulations and waste management, as well as international organizations such as WHO, are key recipients of this document. It also targets private sector partners involved in waste treatment technology, and non-governmental organizations (NGOs) that support health initiatives. The document aims to equip these stakeholders with the knowledge and resources they need to select, implement, and finance effective and sustainable waste handling and treatment technologies. By addressing gaps in knowledge, technology, and financing, and by providing operational guidance, training, and capacity building strategies, it seeks to improve laboratory waste management practices, ensuring public health and environmental safety across the continent.

Furthermore, the document facilitates international collaboration by aligning local practices with global standards, building on partnerships with international bodies such as the U.S. CDC and PEPFAR.

Figure 2 Diagram of healthcare laboratories



3. Guiding Principles for Laboratory Waste Management

As the objective of this document is to provide a comprehensive guideline for the selection, implementation, and financing of clinical laboratory waste treatment strategies across all health laboratories in Africa, it is important to consider and apply various guiding principles for laboratory waste management. The World Health Organization has identified five principles that are widely recognized as the basis for the effective and controlled management and treatment of waste. Many countries use these principles in developing their policies, legislation, and guidelines:
The “POLLUTER PAYS” principle implies that all waste producers are legally and financially responsible for the safe and environmentally sound disposal of the waste they produce. This principle also seeks to assign liability to the party causing damage.

The “PRECAUTIONARY” principle is a strong health and safety protection principle. It was defined and adopted as Principe 15 of the Rio Declaration on Environment and Development (UNEP, 1972): “Where there are threats of serious or irreversible damage to the environment, lack of full scientific certainty should not be used as a reason for postponing cost-effective measures to prevent environmental degradation.”

The “DUTY OF CARE” principle states that anyone managing or handling hazardous substances or wastes, or related equipment has an ethical responsibility to exercise the utmost care in doing so. This principle is best achieved when all parties involved in the production, storage, transport, treatment, and final disposal of hazardous waste (including healthcare waste) are appropriately registered or licensed to produce, receive, and handle specified categories of waste.

The “PROXIMITY” principle recommends that hazardous waste should be treated and disposed of as close as possible to its source to minimize the risks associated with its transport. Similarly, each community should be encouraged to recycle or dispose of the waste it produces within its own territorial boundaries, unless it is unsafe to do so. The principle of “Prior Informed Consent” enshrined in various international treaties, aims to protect public health and the environment from hazardous waste. It requires that affected communities and other stakeholders be informed of the hazards and risks and that their consent be obtained. In the context of healthcare waste, the principle could apply to the transport of waste and the siting and operation of waste treatment and disposal facilities.
In addition to the general principles of waste management, it is essential to add two others that have received a lot of attention in recent times. They emphasize the importance of minimizing waste generation, maximizing resource efficiency, minimizing environmental impact, and sustainability.

“EXTENDED PRODUCER RESPONSIBILITY” (EPR) is an important principle in healthcare waste management. The EPR principle is based on the idea that manufacturers have the greatest control over product design and should be responsible for the environmental impact of their products. The EPR adds the estimated environmental costs associated with a product throughout its life cycle to the cost of the product. It is applied in the waste management sector and aims to relieve local authorities of the costs of managing certain priority products by requiring manufacturers to take responsibility for the entire life cycle of the product, in particular for the take-back, recycling, and final disposal.

“ENVIRONMENTAL STEWARDSHIP” on the other hand, is the act of minimizing the health, safety, environmental, and social impacts of a product and its packaging throughout its life cycle while maximizing economic benefits. Moreover, laboratories can also adopt environmental stewardship practices by implementing waste segregation and reduction strategies, promoting the use of reusable products, and ensuring the proper disposal of healthcare waste.
In developing a sustainable waste management program, it is necessary to refer to and develop the guiding principles outlined above. The overriding principle governing the careful handling of laboratory waste is that no activity should begin until procedures and practices for the safe handling, treatment and disposal of non-hazardous and hazardous waste have been implemented in accordance with the principles developed above.

4. Regulatory Frameworks

Healthcare waste management (HCWM) is crucial due to the inherent risks posed by its physical, biological, and chemical hazards. Effective HCWM systems rely on a solid regulatory framework that governs the safe handling, treatment, and disposal of such waste. These frameworks are often based on international guidelines and are essential for developing and sustaining HCWM systems.

International Guidelines and Frameworks

Many African countries adhere to international conventions and guidelines for HCWM, incorporating recommendations from various organizations such as:

- World Health Organization (WHO)
- US Centers for Disease Control and Prevention (CDC)
- United Nations Children's Emergency Fund (UNICEF)
- United Nations Environmental Programme (UNEP)
- United Nations Development Programme (UNDP)
- United States Agency for International Development (USAID)
- United Nations Global Environment Facility (UN-GEF)

These organizations provide valuable guidelines and frameworks that help shape national HCWM systems. The integration of these international standards into national regulations has been instrumental in supporting the development of robust HCWM systems across Africa. (Figure 3)

Challenges in Low- and Middle-Income Countries (LMICs)

Despite these international guidelines, many low- and middle-income countries (LMICs) face significant challenges in maintaining effective HCWM systems. Common issues include:

Misalignment with Local Contexts

The solutions and technologies recommended by international guidelines may not always align with the socio-economic realities of LMICs. This misalignment can hinder the implementation and sustainability of HCWM practices.

Resource Limitations

Establishing a comprehensive HCWM system including segregation, collection, packaging, transport, treatment, incineration, and disposal—requires substantial resources. In many LMICs, limited financial and infrastructural resources make it challenging to build and maintain these systems.

Regulatory Framework Gaps

For HCWM systems to be effective and sustainable, they need to be supported by strong regulatory frameworks that address local conditions and resource constraints. Many countries struggle with implementing and enforcing such frameworks effectively.

Importance of Tailored Solutions

To address these challenges, it is crucial to develop HCWM systems that are tailored to local conditions and resource availability.

A core HCWM system should be established at the national level, incorporating:

- **Segregation:** Proper classification and separation of waste types.
- **Collection:** Safe and efficient collection methods.
- **Packaging:** Secure and compliant packaging of waste.
- **Transport:** Safe transport procedures.
- **Treatment:** Appropriate treatment methods.
- **Incineration:** Safe and effective incineration processes.
- **Disposal:** Responsible disposal practices.

By ensuring that HCWM solutions are practical, sustainable, and aligned with local contexts, countries can enhance the effectiveness of their waste management systems and protect public health and the environment.

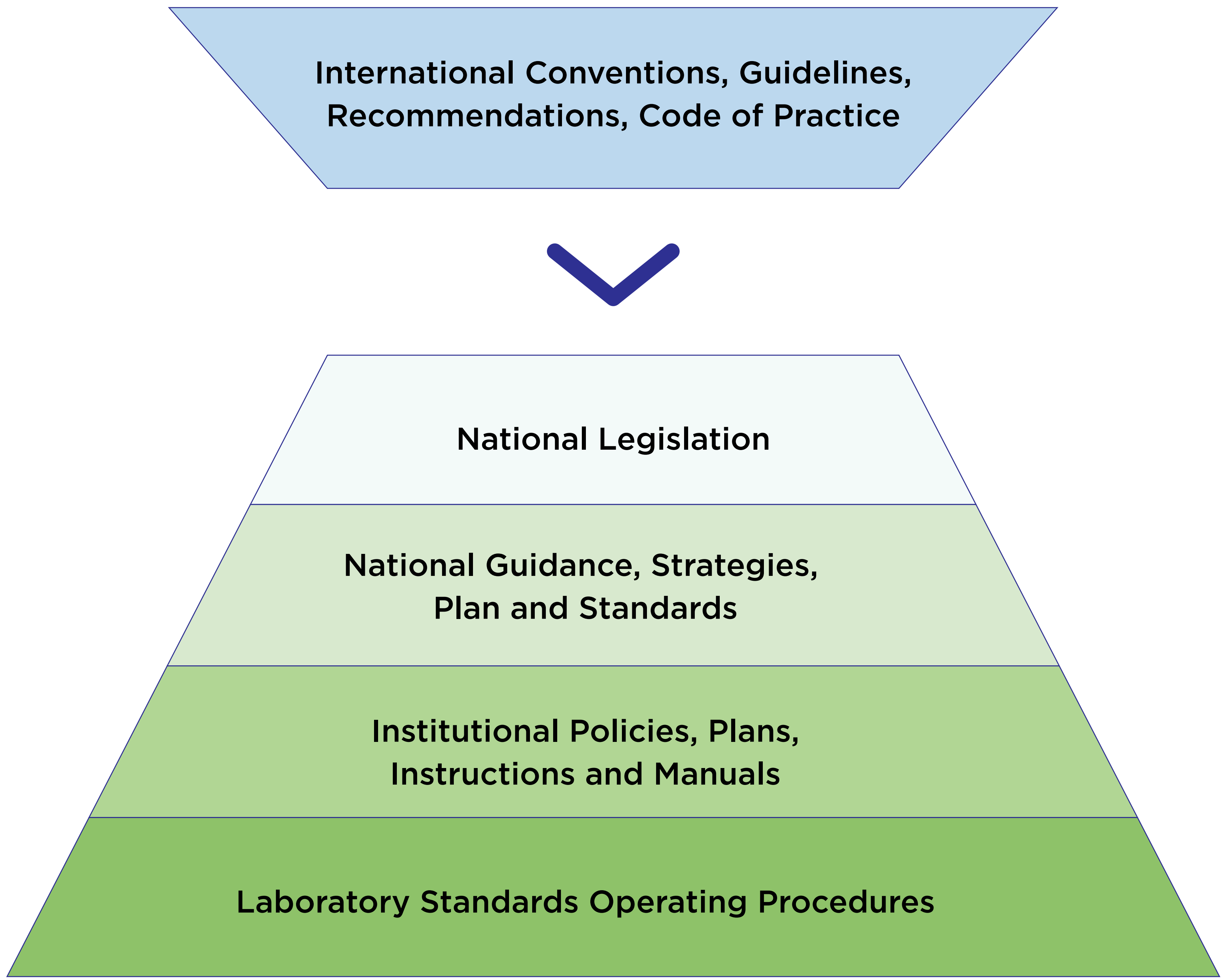


Figure 3 - Example of structure of Regulatory Frameworks

5. Laboratory Waste Management Responsibilities

The management and treatment of laboratory waste is a critical aspect of ensuring safety and compliance in a laboratory environment. The level of responsibility for laboratory waste management involves multiple parties at national and institutional levels. By effectively implementing these responsibilities at both the national and institutional levels, laboratory waste management and treatment can be carried out in an environmentally sound manner, ensuring the protection of human health and the conservation of natural resources (Figure 4).

5.1 National Level

a) **Enactment of legislation:** National governments are responsible for establishing and enforcing laws and regulations related to laboratory waste management. This includes setting guidelines for waste classification, handling, treatment, storage, and disposal.

b) **Regulatory authorities:** National regulatory authorities are responsible for monitoring and ensuring compliance with waste management regulations. They oversee the licensing and inspection of laboratories to ensure proper waste management practices.

c) **Education and awareness:** Governments should promote education and awareness programs to inform laboratory personnel of the importance of proper waste management practices. This can be achieved through workshops, training programs, and the distribution of educational materials.

d) **Support research and development:** National governments should invest in research and development of innovative waste management technologies to minimize the environmental impact of laboratory waste. This includes supporting the development of sustainable waste treatment and recycling methods.

5.2 Institutional Level

a) **Waste management plan:** Institutions should develop and implement a comprehensive laboratory waste management plan. This plan should outline procedures for waste segregation, handling, storage, treatment, and disposal in accordance with national regulations.

b) **Training and education:** Institutions have a responsibility to provide training and education to laboratory personnel on waste management practices. This includes dissemination of information on waste segregation, proper labeling, and the use of appropriate personal protective equipment.

c) **Monitoring and auditing:** Institutions should establish systems to regularly monitor and audit their waste management practices on a regular basis. This will help to ensure compliance with regulations, identify areas for improvement, and promote continuous evaluation of waste management procedures.

d) **Waste minimization and recycling:** Institutions should prioritize waste minimization strategies by promoting the reduction of hazardous inputs and the reuse of non-hazardous materials. They should also explore opportunities for recycling, such as implementing solvent recovery programs or recycling electronic waste.

e) **Collaboration with local authorities:** Institutions should collaborate with local waste management authorities to ensure the safe and appropriate disposal of laboratory waste. This may include establishing partnerships with waste management companies or participating in local waste management programs.

5.3 Community Level

a) **Engagement and Awareness:** Communities, especially those near laboratories and waste disposal sites, must be made aware of the potential risks posed by laboratory waste. Laboratories and institutions should engage with the public to provide information on the health and environmental risks of improper waste disposal.

b) **Advocacy for Environmental Justice:** Communities should be involved in advocating for environmental justice, ensuring that vulnerable populations are not disproportionately affected by improper laboratory waste management practices.

c) **Participatory Waste Management:** Local communities can participate in waste management planning processes, contributing to decisions regarding disposal sites and safety measures that minimize the environmental impact on their surroundings.

d) **Reporting Unsafe Practices:** Communities should be empowered to report unsafe or illegal waste disposal practices to local authorities, ensuring accountability from laboratories and waste management entities.

5.4. International and Regional Cooperation Level

a) **Cross-Border Collaboration:** The complexities of laboratory waste management require cross-border cooperation. African laboratories, governments, and institutions must work together to develop regional solutions to shared challenges.

b) **Standardization of Practices:** International organizations like ASLM, WHO and Africa CDC can help to harmonize waste management practices across African countries. This ensures that best practices are applied consistently.

c) **Capacity Building and Knowledge Sharing:** International partnerships can facilitate the sharing of knowledge and resources, including new waste management technologies, training programs, and funding opportunities.

d) **Access to Technical Assistance:** International agencies can provide technical support to African laboratories, helping them meet global biosafety standards and access advanced waste management systems.

The roles and responsibilities in the laboratory waste management (LWM) system are divided, and the success of the establishment and functioning of the LWM system depends directly on the active participation of all actors. The following table is provided as an example to illustrate general roles within a laboratory waste system. Specific roles and responsibilities may vary according to country-specific regulations and organizational structures (Table 1).

Table 1 - Example of general roles and responsibilities for the safe management of laboratory waste

Director of the Laboratory facility (Executive manager)	- leads responsibility for the implementation of laboratory waste management guidelines or policies - provide resources to support the implementation of the LWM guidelines or policy - monitors the work of the management board and instructions related to LWM activities
WM Committee (Supervision)	- oversees the overall LWM - receives specific questions regarding the implementation, development and monitoring of LWM - reviews all policies, guidelines, and procedures for LWM - supports the implementation and monitoring of guidelines - provides support and advice to all staff involved in the LWM as required - receives all complaints related to this area of practice and policy
Environmental officer or Laboratory waste management operational manager	- ensures LWM in accordance with national guidelines - ensures that responsible individuals and groups are fully informed of their role in maintaining the required standards of practice - provides day-to-day management for all aspects of the safe and secure handling of LWM - leads strategies and innovations to improve current practice - owns the development and implementation of standard procedures for LWM
Heads of Department in Laboratory facilities/Heads of different laboratories Managers (Operational management)	- coordinate and implements LWM activities in all relevant departments and services within their groups - provide sufficient training and skills to implement the guidelines - discuss LWM activities and ways to improve them - provide up-to-date information on practices and policies
Quality and Safety Departments (Monitoring)	- monitor and review all incidents, complaints and allegations related to this area of practice - review the practice to ensure that it is being applied appropriately and in accordance with this guidance - plan to implement changes to the current practice and revise the guidance if necessary
Personnel involved in the day-to-day generation, storage and safe disposal of LWM (implementation of guidelines)	- attend appropriate training applicable to their role - ensure the implementation of adequate procedures during the work related to the LWM - accept suggestions from staff concerned about the way in which this guidance is being implemented or about this area of practice in general

6. Identification and Classification of Laboratory Waste

6.1. Identification of laboratory waste

Laboratory waste is a specific category within the broader spectrum of healthcare waste, which includes various materials generated by laboratory procedures and tests. Healthcare waste itself includes all waste generated by healthcare activities, broadly categorized into general non-hazardous waste and hazardous waste. Hazardous waste includes infectious waste, pathological waste, sharps, chemical waste, pharmaceutical waste, cytotoxic waste, and radioactive waste (Table 2). Laboratory waste includes materials such as used culture plates, specimen containers, chemical reagents, glassware, and other items contaminated with potentially infectious agents or hazardous chemicals (Table 3).

Table 2 Wastes streams in healthcare[5]

Waste category	Other used terms	Descriptions and examples
		Hazardous healthcare waste
Sharps waste		Used or unused sharps (e.g. hypodermic, intravenous or other needles; auto-disable syringes; syringes with attached needles; infusion sets; scalpels; pipettes; knives; blades; broken or unbroken glass waste)
Infectious waste	Infective, Bio-medical, Clinical	Waste suspected of containing pathogens and posing a risk of disease transmission (e.g. waste contaminated with blood and other body fluids; laboratory cultures and microbiological stocks; waste including excreta and other materials that have been in contact with patients infected with highly infectious diseases in isolation wards)
Pathological waste	Anatomical	Human tissues, organs, or fluids; body parts; fetuses; unused blood products
Pharmaceutical waste		Expired or unwanted pharmaceuticals; items contaminated by or containing pharmaceutical residues
Cytotoxic waste	Genotoxic, cytostatic	Cytotoxic waste containing substances with genotoxic properties (e.g. waste containing cytostatic drugs – often used in cancer therapy; genotoxic chemicals)
Chemical waste		Waste containing chemical substances (e.g. laboratory reagents; film developer; disinfectants that are expired or no longer needed; solvents; waste with heavy metal content, e.g. batteries; broken thermometers and blood-pressure monitors)
Radioactive waste	Nuclear	Waste containing radioactive substances (e.g. unused liquids from radiotherapy or laboratory research; contaminated glassware, packaging, or absorbent paper; urine and excreta from patients treated or tested with unsealed radionuclides; sealed sources)
Other special hazardous waste streams		Waste from electrical and electronic equipment, safety cabinets, fluorescent bulbs, refrigerators and transformers, AC units, various filters, and filter sections
Non-hazardous or general healthcare waste	Municipal, household solid waste	Waste that does not pose any biological, chemical, radioactive, or physical hazard

Table 3 Laboratories, common samples analyzed and waste streams

Laboratory	Common Sample	Common waste streams
Chemistry	Blood / Body fluids	Blood tubes, specimen tubes, plastic tubes, pipette tips, platform related disposables, PPE, platform effluent, platform chemicals
Hematology / Coagulation	Blood	Blood tubes, specimen tubes, plastic tubes, pipette tips, platform related disposables, PPE, glass slides, cover slips, swab stains, platform effluent, platform chemicals,
Serology	Blood	Blood tubes, applicator sticks, capillary tubes, blood dispensers, platform related disposables, PPE, platform effluent, platform chemicals,
Histology / Cytology	Tissues / Body fluids / biopsies	Tissues, specimen containers for body fluids, scalpel blades, microtome blades, glass slides, tissue blocks, solvents, fixatives, and stains, empty chemical bottles, PPE
Immunology	Blood	Blood tubes, specimen tubes, plastic tubes, pipette tips, platform related disposables, PPE, platform effluent, platform chemicals
Microbiology*	Body fluids / Blood / Swabs	Blood culture bottles, syringes with needles, culture plates/tubes, liquid growth media, glass slides, coverslips, loops, stains, microtiter plates, cartridges, platform related disposables
Molecular testing	Blood, swabs, sputum etc.	Molecular testing is an integral part of various laboratory segments and generates the following waste streams: Blood tubes, specimen tubes, plastic tubes, pipette tips, platform related disposables, cartridges, PPE, platforms effluent, platform chemicals
Blood Bank	Blood and blood products	Needles, lancets, tubes of blood and blood products, plastic tubes, tubing, wooden sticks, gel cards, units of expired blood products, PPE
Environmental samples and waste streams	Water, Soil, and Air	Ash from incineration, contaminated materials, samples, reagents, solvents, and other chemicals used in laboratory analysis,

* Mycobacteriology, Mycology, Parasitology, and Virology

The most common sample used in laboratories is blood. Urine is also often tested followed by the range of body fluids and excretions/ secretions (sputum and feces). Swab samples can be taken from various parts of the human and animal body such as skin, throat, vagina, ears, and sites of infection. Finally, tissue samples such as skin tags, biopsies, or tumors. "The table above (Table 3), listing various sample and medical waste streams, and the table below (Table 4) listing different chemical hazard categories is not intended to be an exhaustive list of all wastes generated in medical laboratories and provides only brief descriptions of generated waste stream

Table 4 Chemical waste management – Categories and treatment options

Category	Example	Handling and storage	Treatment and disposal
Toxic 	Mercury Ethyl acetone Formaldehyde Ethidium bromide	Store in containers suitable for chemicals (plastic, metal, or glass); Use appropriate hazard symbols; Store at cool temperatures in well-ventilated areas	Recycling Neutralization Incineration Hazardous landfill
Flammable 	Alcohols Acetic acid Acetone	Store in containers suitable for chemicals (plastic, metal, or glass); Use appropriate hazard symbol. Store at cool temperatures in well-ventilated areas	Recycling Neutralization Hazardous landfill Incineration
Corrosive 	Hydrochloric acid Sodium hydroxide Sodium hypochlorite	Store in containers suitable for chemicals Use appropriate hazard symbol. Store at cool temperatures in well-ventilated areas	Neutralization Hazardous landfill Incineration
Oxidizer 	Hydrogen peroxide Peracetic acid	Store in containers suitable for chemicals (plastic, metal, or glass); Use appropriate hazard symbol. Store at cool temperatures in well-ventilated areas	Neutralization Hazardous landfill Incineration

6.2 Classification of laboratory waste

Waste identification and classification is the most critical activity in healthcare waste management. Identifying the hazard factors of the waste to facilitate classification can be achieved by conducting a risk assessment. Laboratory waste classification takes a risk- and evidence-based approach to biosafety rather than a prescriptive approach based on biosafety levels 1-4, to ensure that laboratory facilities, safety equipment and work practices are locally relevant, proportionate, and sustainable.

WHO guidelines[6] categorize laboratory waste into several types: infectious waste, which includes waste contaminated with blood and other body fluids; pathological waste, such as tissues and organs; sharps, including needles and broken glass; chemical waste, which includes discarded chemicals and reagents; and radioactive waste from laboratories that use radioactive substances. Each category requires specific handling, treatment, and disposal procedures to mitigate the associated risks.

The United Nations (UN) has a numerical identification system for classifying dangerous goods to be transported (Table 5). The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes has a similar classification system (see Annex).

Table 5 UN Classes of Dangerous Goods

UN Class	Dangerous Goods	Division (s) if applicable	Classification
1	Explosives	1.1 - 1.6	Explosives
2	Gases	2.1	Flammable gas
2	Gases	2.2	Non-flammable gas, non-toxic gas
2	Gases	2.3	Toxic gas
3	Flammable liquids	3	Flammable liquid
4	Flammable liquids	4.1	Flammable solid
4	Flammable liquids	4.2	Spontaneous combustible substance
4	Flammable liquids	4.3	Substance which emits flammable gas in contact with water
5	Oxidizers and Organic peroxides	5.1	Oxidising substance
5	Oxidizers and Organic peroxides	5.2	Organice peroxide
6	Toxic and infectious substances	6.1	Toxic substance
6	Toxic and infectious substances	6.2	Infectious substance
7	Radioactive material	7	Radioactive material
8	Corrosive materail	8	Corrosive material
9	Miscellaneous dangerous substance and articles	9	Miscellaneouus dangerous substances and articles

Examples of UN four-digit numbers used to identify dangerous goods for transport:

Category A substances include

UN2814, Infectious substances affecting humans

UN2900, Infectious substances affecting animals

UN3549 Regulated medical waste not otherwise specified

(Category A substances produced from the medical treatment of humans or animals)

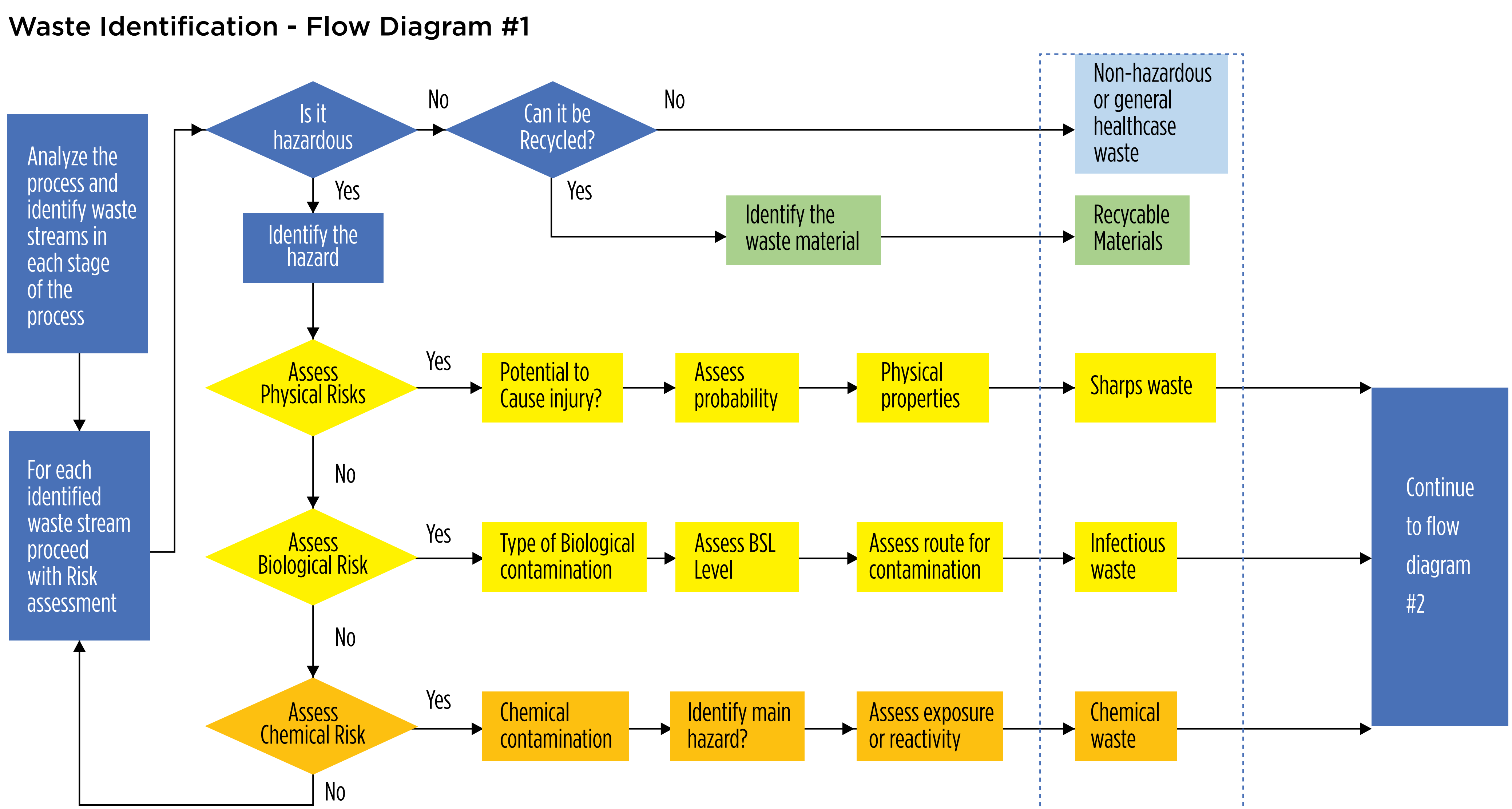
Category B substances include:

- UN3733, Biological substances, Category B
- UN3291, REGULATED MEDICAL WASTE, (N.O.S.)*, (Category B substances produced from the medical treatment of humans or animals)4

*N.O.S. – Not Otherwise Specified

An example of a waste identification and classification process, based on the evaluation and exclusion of hazardous properties, applicable to healthcare waste and only for descriptive purposes only, is shown in Figure 5 below.

Figure 5 Waste Identification - Flow Diagram #1

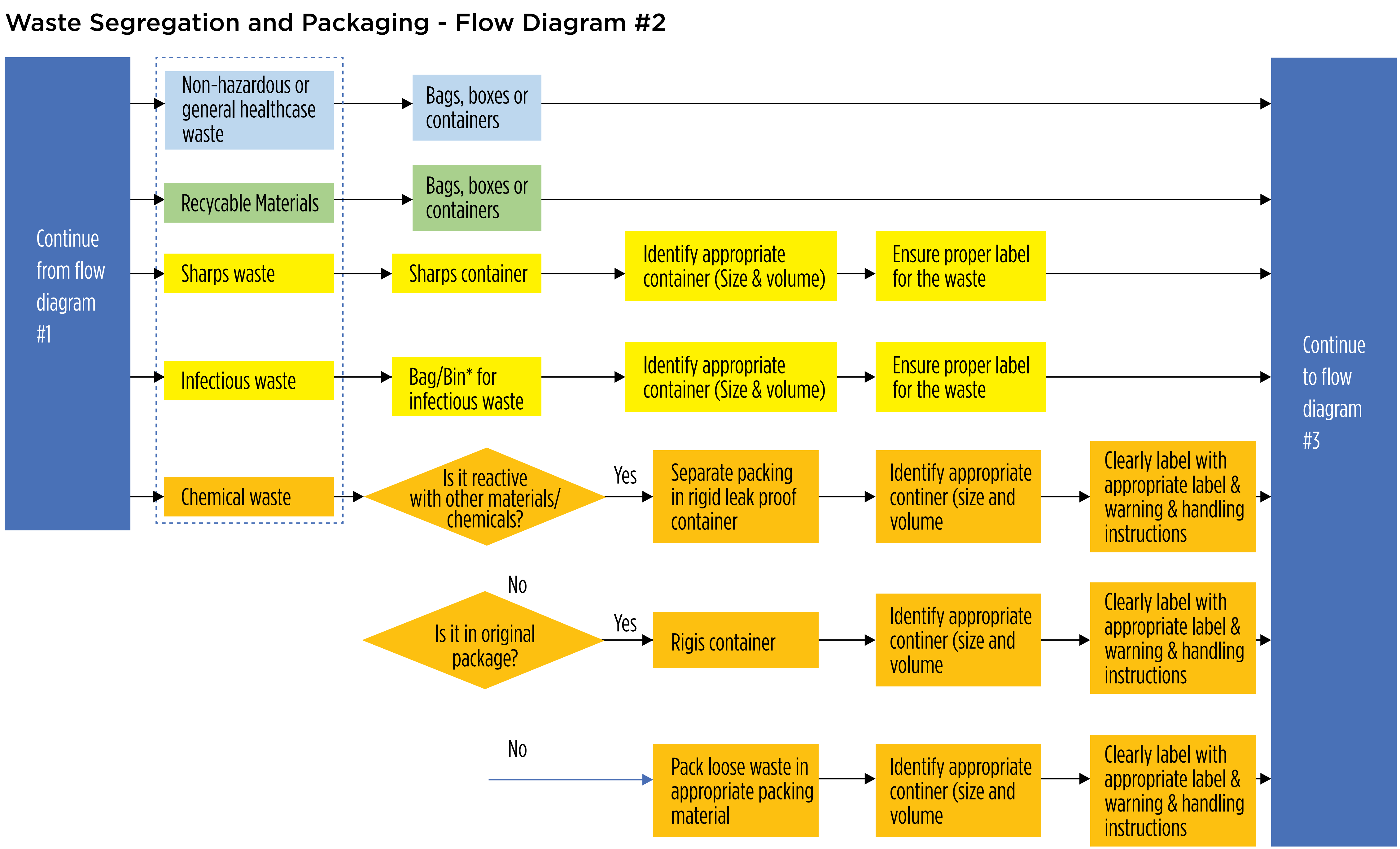


6.3 Waste segregation

Laboratory waste is segregated according to risk classification to ensure safe handling, treatment, and disposal. Proper segregation minimizes the risk of exposure to hazardous substances and facilitates the effective management and treatment of the waste. For effective segregation, different types of packaging and containers are recommended for different waste streams. Infectious waste should be placed in leak-proof, puncture-resistant containers that are clearly labelled with a biohazard symbol. Pathological waste, such as tissues and organs, should be stored in sealed, leak-proof containers and kept refrigerated if not processed immediately. Sharps should be disposed of in rigid, puncture-resistant containers to prevent injuries and contamination. Chemical waste should be stored in corrosion-resistant containers with clear labelling of the contents and associated hazards (Table 4). Pharmaceutical waste requires containers that prevent leakage and are that are labelled to distinguish between different types of pharmaceutical products. Cytotoxic waste should be stored in specially marked containers indicating the presence of cytotoxic substances, and radioactive waste must be stored in containers that provide radiation shielding and that are labelled with the radioactive symbol.

The WHO[5] stresses the importance of using color-coded containers to simplify the segregation process and reduce the risk of mixing different types of waste. For example, yellow bags or containers are typically used for infectious waste, red for sharps, and black for general non-hazardous waste. The color-coding system may vary from country to country. Therefore, producers of waste need to understand and follow local guidance and regulations. This color-coding system helps ensure that all personnel can easily identify the appropriate disposal methods for each type of waste, promoting a safer working environment.

Figure 6 Waste Identification - Flow Diagram #2



Color-coding and packaging requirements

Each country has the authority to establish specific color-coding and packaging requirements for each category of laboratory waste, which must align with international recommendations for the safe transport of dangerous goods. According to the WHO[7] proper packaging of waste is essential to contain its hazardous properties and ensure safe handling during transport and treatment.

Packaging must be durable and designed to withstand the various stresses encountered during handling and transport. Key considerations include:

- **Volume of waste:** Determine whether the waste is generated in high or low volumes to select appropriately sized containers.
- **Sharps waste:** Assess whether the waste contains sharp objects, which will require puncture-resistant containers. (Figure 7)
- **Moisture content:** Determine whether the waste is wet, dry, or mixed, requiring leak-proof or moisture-resistant packaging.
- **Waste forms:** Consider whether the waste is in dust, solid, or liquid form, which will affect the type of containment required.
- **Weight of waste:** Assess whether the waste is heavy or light to ensure the packaging can support the weight without breaking.
- **Need for single or double packaging:** Determine if double packaging is required to provide an extra layer of protection. (Figure 8)
- **Additional symbols or labels:** Assess the need for additional symbols or labels to better identify of the waste contents and **associated hazards.**
- **Need for bins:** Step cans (Figure 9) or wheeled bins (Figure 10)

Figure 7 Sharps containers

Figure 8 Plastics Biohazard bags

Figure 9 Step cans

Figure 10. Wheeled bins

General recommendations include the use of thoroughly tested and certified UN-approved packaging. These packages should bear the appropriate UN code to indicate compliance with international standards. For example, infectious waste should be packaged in containers marked with the biohazard symbol, while chemical and pharmaceutical waste should have special labels indicating their hazardous nature (Figure 11).

Figure 11 UN Dangerous Goods - Marking of Transport packaging/container - marking for solids

6.4 Storage requirements

According to international guidelines and conventions, the following practices as shown in Figure 12 below must be implemented for the proper storage of laboratory waste:

Temporary storage area: Laboratory waste should be temporarily stored within the laboratory premises for no more than one working shift. This area must be clearly identified with appropriate signs and labels to ensure safety and compliance with WHO guidelines on waste segregation and labelling.[8] Proper identification helps prevent accidental exposure and ensures that all personnel are aware of the presence of hazardous materials.

Equipment and containers: The temporary holding area must be equipped with durable transport containers designed for easy handling and transport of collected waste. Containers shall be puncture-resistant, leak-proof, and appropriately labelled to indicate the type of waste they contain. This will help prevent spills, leaks, and injuries during transport.

Capacity and practice: The storage area must have sufficient capacity to store all waste in accordance with the institution's established practices and waste management plans. It should be flexible enough to accommodate fluctuations in waste volumes, following the Basel Convention's recommendations for adequate waste management infrastructure (Basel Convention, 1989). This will ensure that there is no overflow of waste, which could lead to contamination and health hazards.

Central storage areas: Central storage areas need to be secured to protect the waste from the natural elements, animals, and unauthorized access. They should also have extra space for stockpiling during peak waste generation periods, as required by WHO guidelines. Secure storage prevents unauthorized access that could lead to mishandling handling or illegal disposal of hazardous waste.

Ventilation: Central storage areas should be well ventilated to maintain a low ambient temperature, reducing the risk of odour nuisance and accelerated decomposition of waste. This is in line with WHO guidelines for minimizing health risks associated with waste storage. Proper ventilation helps remove harmful fumes and maintain air quality, protecting both the environment and human health.

Flooring and cleaning facilities: Floors must be impervious, slip-resistant, and hard-standing to facilitate easy cleaning. A nearby water source is required for cleaning, with a good drainage connection to a sewerage system to maintain hygiene and prevent contamination. An easy-to-clean surface helps maintain a hygienic environment and prevents the build-up of harmful pathogens.

Accessibility and lighting: Central storage areas must be well lit, conveniently located, and free from obstructions to always ensure easy access for waste collection vehicles, for safe access and handling of hazardous materials. Good lighting ensures that the waste operator can handle the waste safely and correctly, reduces the risk of accidents, and ensures that all labels and signs are clearly visible.

Location and safety: The central storage area should be in a low-traffic area, away from public spaces and hygienically sensitive areas such as kitchens and laundries. It must be equipped with a fire extinguisher and spill management kits for safety, in line with WHO recommendations. This reduces the risk of contamination in hygienically sensitive areas and ensures that immediate action can be taken in the event of a spill or fire.

Waste Stream identification: Each waste stream must have designated locations within the storage area to prevent cross-contamination and to ensure proper handling, in accordance with WHO guidelines for effective waste segregation. These locations must be clearly marked for each waste stream (e.g., infectious, chemical, radioactive) to minimize improper disposal.

Waste Collection, Internal Transport and Storage - Flow Diagram #3

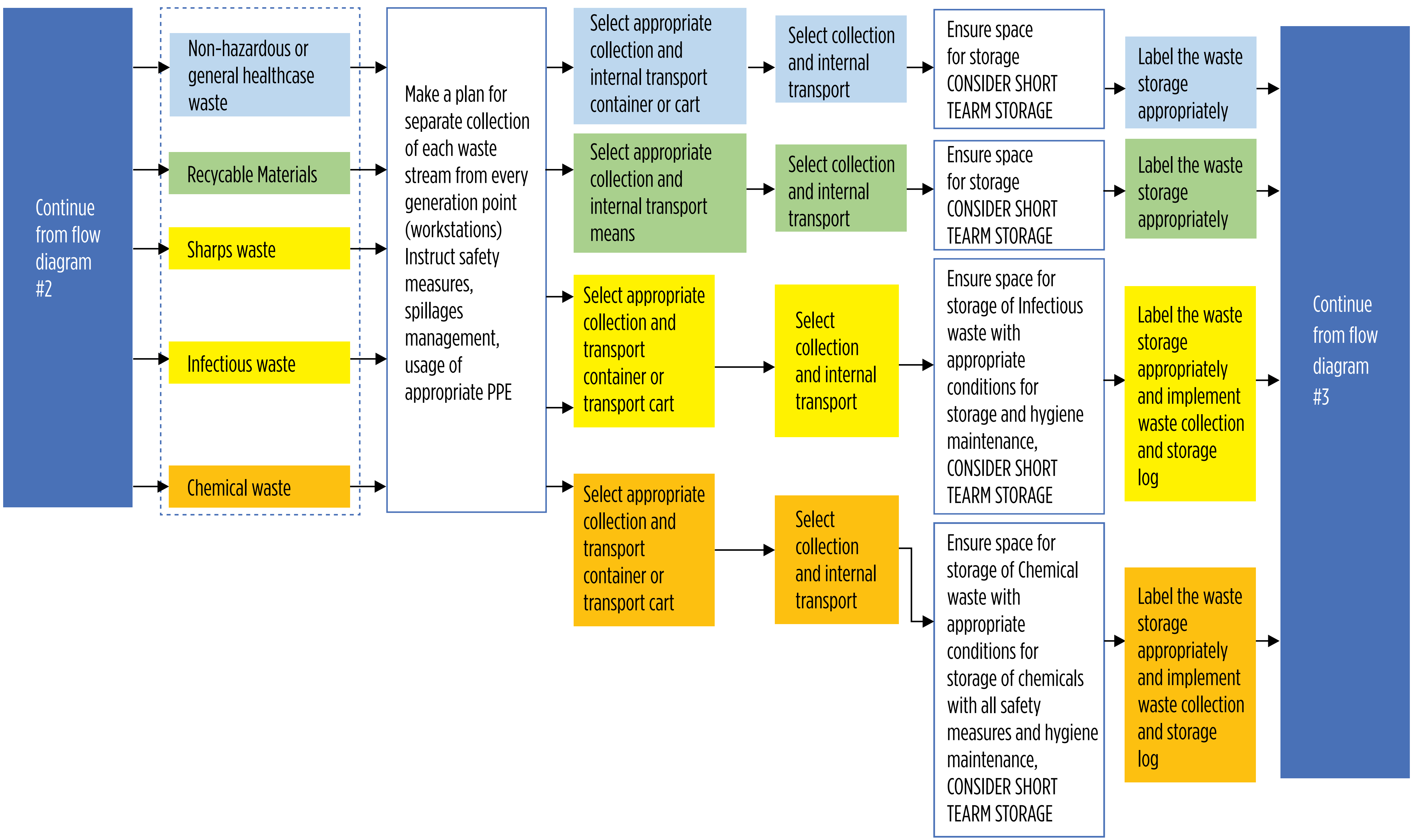


Figure 12 Waste Collection, Internal Transport, and Storage - Flow Diagram #3

6.5 Collection frequency

The frequency of collection should be organized according to the waste streams, generation rates, and applicable regulations. Infectious waste: The recommended collection frequency from central storage should not exceed 48 hours in summer, considering the geographical location of the facility.

Pathological/anatomical waste: This type of waste must be handled with special care, especially when stored in formalin. There are specific recommendations for the storage and handling of anatomical specimens (College of American Pathologists (CAP),[9] all of which emphasize strict procedures and practices. At a minimum, the following considerations must be made:

Ventilation: Ensure that storage areas are well ventilated to prevent the build-up of formalin vapors, which can be harmful if inhaled. Proper ventilation also helps to reduce the characteristic odor associated with formalin.

Temperature: Maintain a constant temperature in the storage area to avoid fluctuations that could affect the integrity of the specimens. Typically, room temperature storage is suitable, but specific guidelines may vary depending on the nature of the specimens. Security: Store the samples in a secure area with limited access to authorized personnel only. This will help prevent accidental exposure and ensure the integrity of the samples.

Chemical waste: This waste can be stored for a maximum of six months. It is important to segregate and package the waste chemicals following their hazardous properties. Always refer to the Safety Data Sheets (SDS) for storage and disposal considerations. The condition of the packaging must be regularly checked and inspected for leaks or damage.

Pharmaceutical waste: Pharmaceutical waste can also be stored for a maximum of six months. It is essential that the pharmaceutical waste be correctly segregated and packaged in accordance with its hazardous properties and the specific requirements of the relevant legislation. Regulated substances, such as anesthetics, antibiotics, or opiates, must be stored separately and secured. The condition of the packaging must be regularly checked and inspected for leaks or damage.

Cytotoxic waste: This type of waste should be stored separately from other healthcare waste in a designated secure location.

6.6 Transport of healthcare waste

Bags or other containers containing infectious waste to be transported must be placed in leak-proof secondary containment during transport. This secondary containment must be adequate to ensure the safe transport of the waste and to prevent any leakage or spillage that could pose a risk to health and safety (Figure 13).

Waste Transport to Treatment, Recycling facility or Disposal facility - Flow Diagram #4

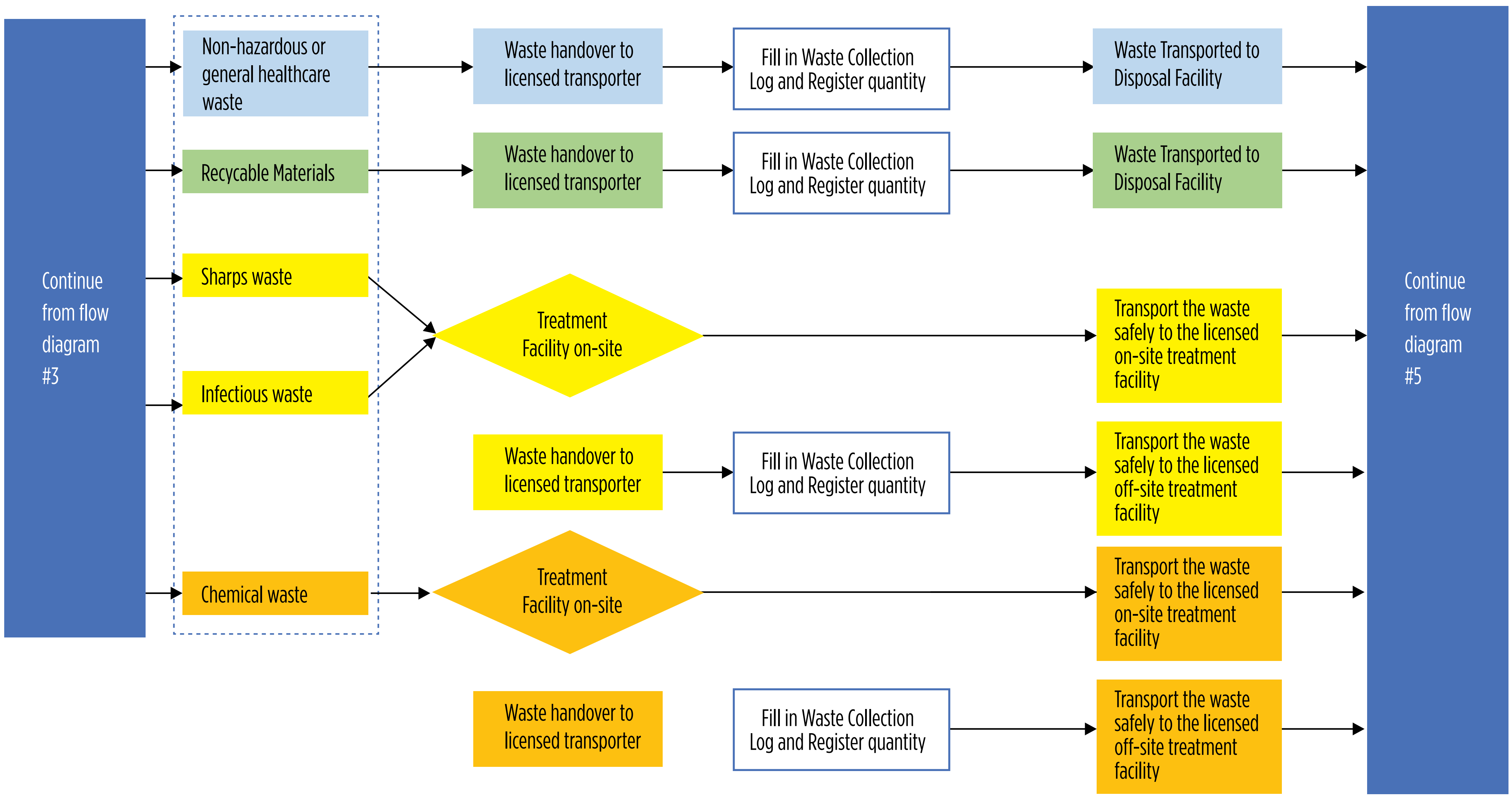


Figure 13 Waste Transport to Treatment, Recycling facility or Disposal facility - Flow Diagram #4

If transport is by vehicle, the following conditions must be met:

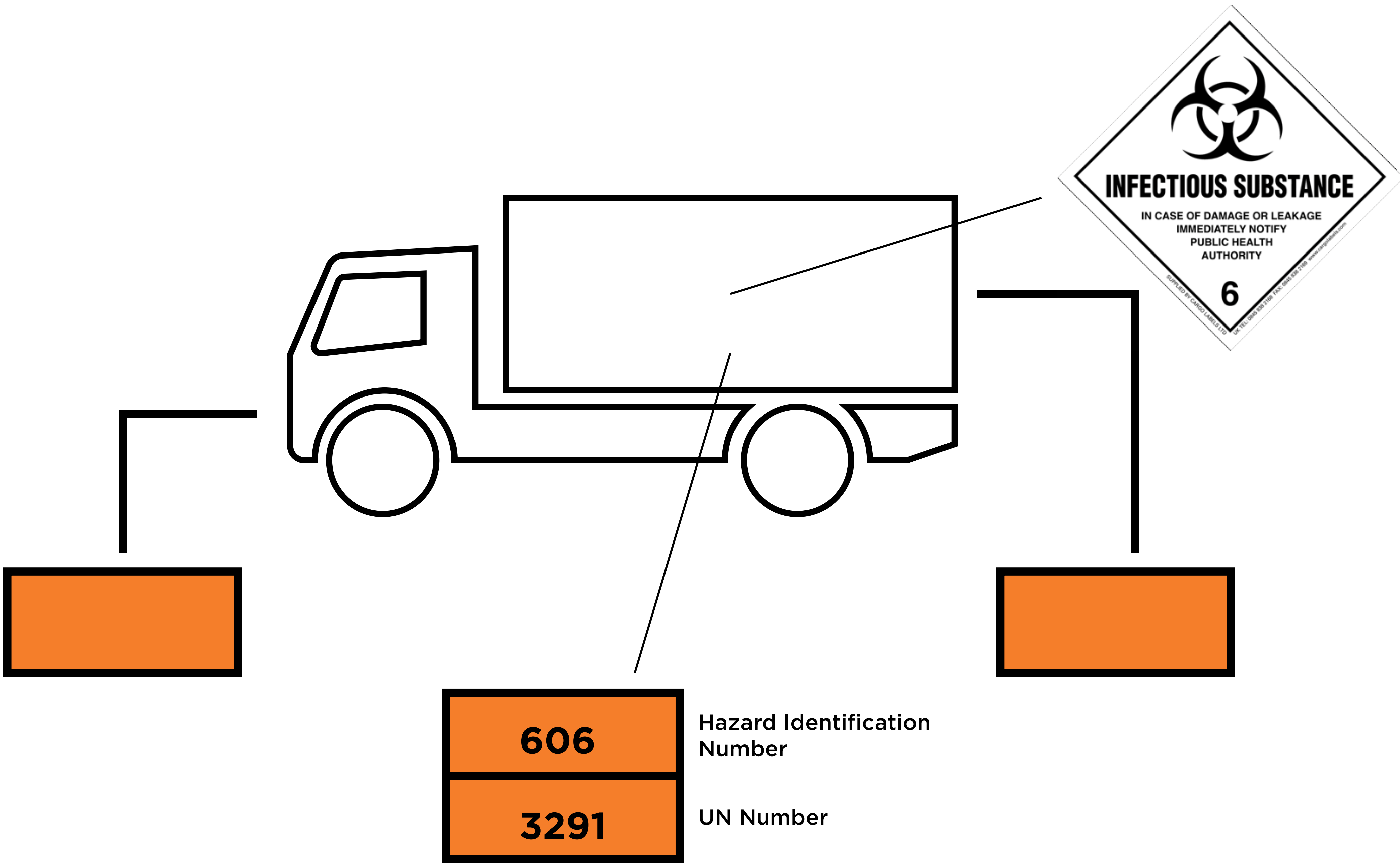
- The secondary container must have a tightly closing lid that remains closed during transport, and appropriate spill containment materials must accompany the waste.
- The vehicle used to transport healthcare waste should not be used to transport other materials.
- The vehicle used to transport the waste should meet the following requirements:
    - Vehicles must be properly maintained and kept clean.
    - Be roadworthy (safe and fit for use on the road)
    - Have a maximum allowable load greater than the expected waste load
    - Be designed for the transport of medical waste.
    - Should be correctly labelled in accordance with national and international legislation, and the name and address of the waste transporter are included.
    - Should have international hazard signs on both sides of the vehicle including an emergency telephone number (Figure 14).
    - The waste containment section of the truck should be leak-proof and airtight (Figure 15)
    - The truck should be a non-compacting truck to avoid destruction of the waste bags.

The following are additional design criteria for transport vehicles:

- The vehicles should have a bulkhead separating the driver's cabin and the vehicle's body.
- The body of the vehicle should be of an appropriate size and designed to retain the waste in the event of an accident.
- The vehicles should have an appropriate system to ensure that waste is secured during transport.
- The internal corners should be rounded so that there are no sharp edges that could damage the waste containers.
- The internal finish of the vehicle must allow for thorough decontamination after use.
- The vehicles must have a separate clean compartment for the storage of plastic bags, PPE, cleaning equipment, tools, disinfectants, and a special kit for dealing with liquid spills.
- The transport vehicles must display warning signs or placards in the locations shown in the pictures below and should carry spare PPE, fire extinguishers, and spill kits
- There may be an opportunity based upon local regulations to utilize 3 wheeled vehicles for local transport (Figure 16)

It is important to follow national guidelines and regulations regarding the transport of different types of healthcare waste.

Figure 14 UN Dangerous Goods - Marking of Transport Vehicle[10]



Transport companies and their staff (drivers, handlers etc.) must fulfill the following requirements to transport healthcare waste:

- The company must be licensed to transport medical waste
- Drivers must be licensed to drive the specific type of vehicle used to transport the waste.
- Staff should be trained and certified in the transport of HCW.
- Staff should have a medical certificate stating that they are fit to handle medical waste.

Staff should be trained in the following:

- Waste classification
- Risks of hazardous waste
- Safe handling of the waste and use of appropriate PPE
- Labeling and documentation
- Emergency spill management procedures
- Emergency service contact numbers

Figure 15 Waste treatment example of medical waste collection truck

Figure 16 Three-wheel vehicle for waste transport

7. Laboratory Waste Treatment

7.1 Waste treatment facilities and operations

The next step in the waste management process is to treat the waste according to its specific characteristics. Waste treatment facilities play a crucial role in ensuring that waste is treated safely and efficiently, minimizing risks to public health and the environment. Key considerations for waste treatment facilities include:

1. **Type of waste:** Different types of waste require different treatment methods. For example, biological waste may require autoclaving or chemical disinfection, while chemical waste might require neutralization or specialized treatment and disposal methods.
2. **Regulatory compliance:** Facilities must comply with local, national, and international regulations regarding waste treatment and disposal. Compliance ensures that the facility operates within the legal framework and minimizes environmental impact.
3. **Environmental Impact:** Treatment processes should be designed to minimize emissions, reduce energy consumption, and effectively manage by-products. Sustainable practices help protect the environment and reduce the facility's carbon footprint.
4. **Operational efficiency:** Efficient operations are essential for cost-effective waste management. This includes optimizing treatment processes, maintaining equipment, and ensuring that staff are well trained.

There are two primary models for the location of waste treatment: on-site and off-site. Each model has different considerations and implications for safety, efficiency, and environmental impact.
On-site model (Figure 17): In this approach, the waste is treated within the facility. An on-site treatment facility should be located away from patient-care service areas to avoid potential contamination and to ensure safety. On-site treatment can also refer to a facility located on the site but separate from the primary operational areas. This model can significantly reduce transport at costs and the environmental impact associated with waste transport. Common on-site treatment methods for infectious waste include autoclaving, chemical disinfection, and microwave treatment.

Off-site model (Figure 18): Waste is transported to an off-site facility for treatment. The location of the off-site facility should be carefully evaluated to ensure that it meets all the transport and logistics requirements of the waste generator. This evaluation is critical to achieving optimal environmental and economic performance. Off-site treatment facilities often have more extensive and specialized equipment that can handle larger volumes of waste more efficiently. Typical off-site treatment methods include incineration, advanced thermal treatment, and high-capacity autoclaving.

The following factors are also crucial in ensuring the continuous operation of a waste treatment facility:

- **Space:** Sufficient space is required to accommodate all necessary treatment processes, storage areas, and potential future expansion. This includes areas for equipment, waste storage, staff facilities, and access to transport vehicles.
- **Location:** The facility should be strategically located to minimize transport costs and associated risks. It should be located away from residential zones, environmentally sensitive areas, and patient care services to reduce potential hazards.
- **Water supply:** A reliable and adequate water supply is critical for various treatment processes, cleaning, and sanitation activities.
- **Sewerage and wastewater treatment:** Efficient sewer systems or connections to wastewater treatment facilities are necessary to manage liquid waste and prevent environmental contamination.

- **Power supply:** A stable and adequate power supply is essential for the operation of the facility. This can be provided by a direct connection to the electrical grid and/or an emergency generator for backup power.
- **Fuel supply:** If the treatment processes require fuel, a consistent and reliable fuel supply must be ensured to maintain continuous operation.
- **Contingency plan:** A detailed contingency plan should be in place to provide alternative treatment options during maintenance or unexpected breakdowns to ensure that waste treatment operations are not interrupted.

Each treatment facility will need to obtain approvals and permits from the relevant authorities in the country to ensure compliance with local regulations and standards. This permitting process typically includes assessments of environmental impact, safety measures, and operational efficiency.

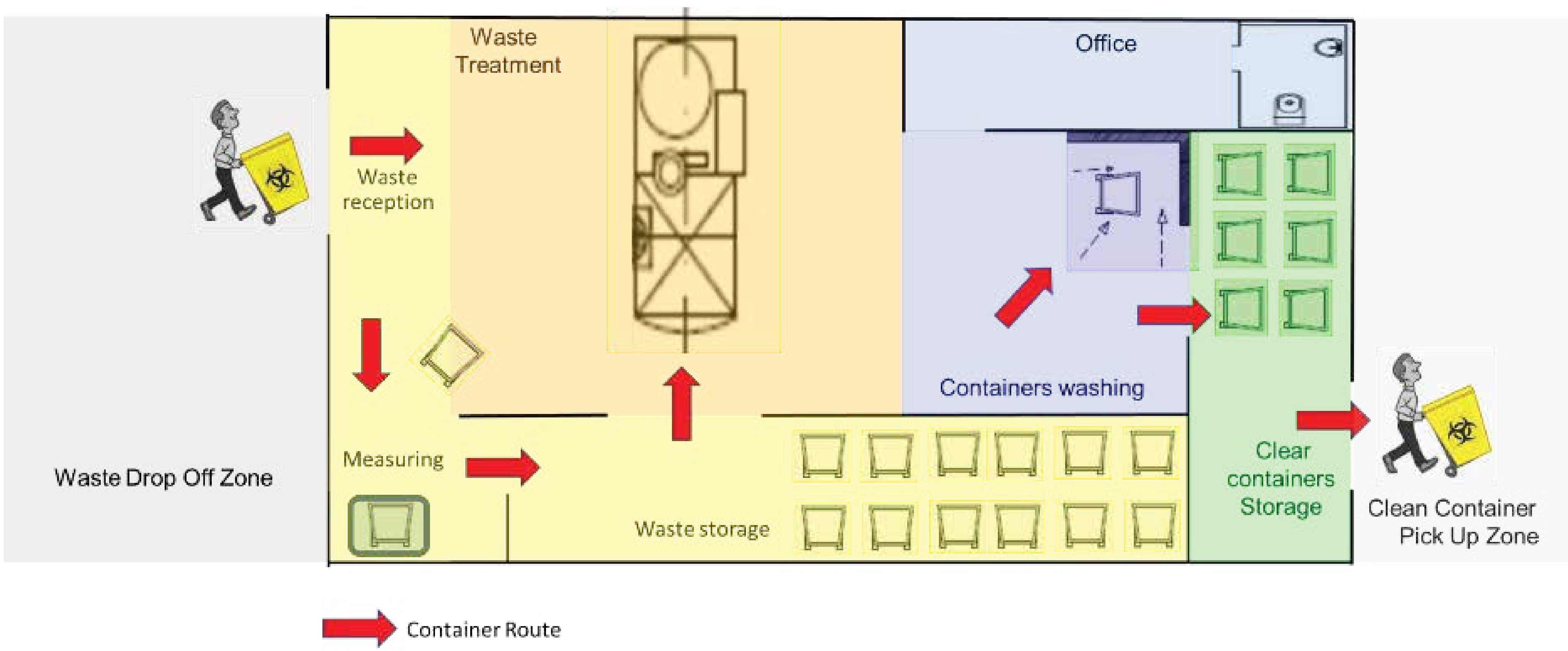


Figure 17. Example of waste process flow for setting up healthcare/laboratory waste on- site treatment facility

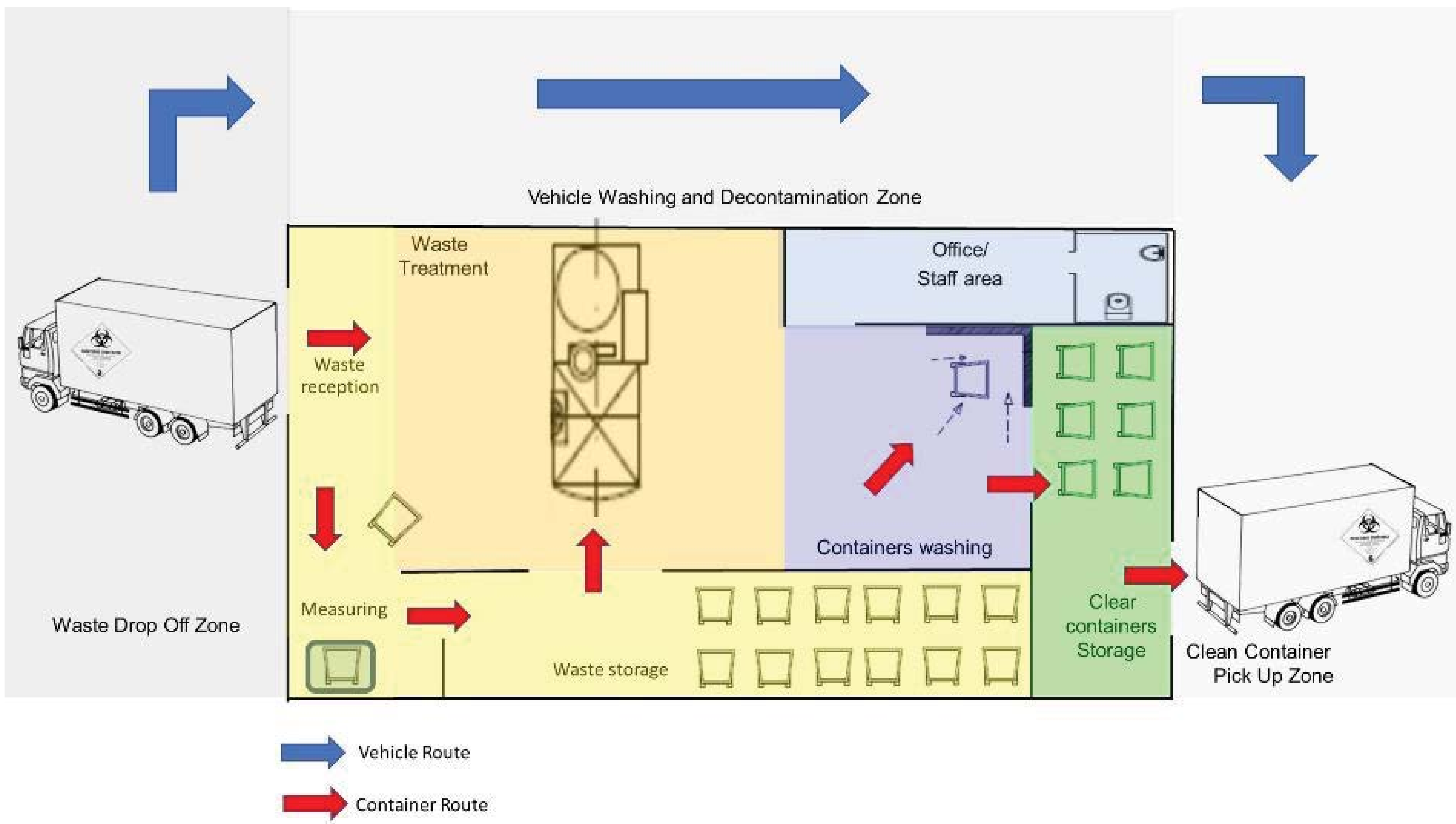


Figure 18 Example of waste process flow for setting up healthcare/laboratory waste on- site treatment facility

7.2 Waste treatment facility design

The design of facilities for healthcare waste treatment, both on-site and off-site, must meet certain critical requirements to ensure safety, efficiency, and environmental compliance. Onsite facilities, typically located within hospitals or laboratories, must include secure storage areas that are clearly marked and separated from other areas of the facility to prevent contamination. These areas should have impermeable floors, adequate ventilation, and be equipped with appropriate waste segregation containers to facilitate the separation of hazardous and non-hazardous waste (Figure 19). The design must include provisions for the regular and safe removal of waste to avoid accumulation. In addition, on-site treatment processes, such as autoclaving, incineration, or chemical disinfection, should be selected based on the types of waste generated and must comply with national and international health and safety standards.

Off-site healthcare waste treatment facilities, which handle waste from multiple healthcare facilities, require a more extensive infrastructure. These facilities need to be strategically located to balance accessibility and environmental safety to minimize the risk to nearby communities. They should also be equipped with advanced treatment technologies that can handle large volumes of waste, such as high-capacity incinerators, advanced autoclaves, or chemical treatment systems. These facilities require more stringent and robust transport systems to ensure that waste is moved safely and efficiently from the point of generation to the treatment site. Off-site facilities must also have comprehensive monitoring systems to track waste from collection through treatment and disposal, ensuring full compliance with regulatory requirements and providing transparency in waste management processes. (Figure 20)

Figure 19 Off-site storage area

As a minimum, waste treatment facilities should include the following areas into their design (Figures 17 and 18):

Waste reception and registration: A designated area for the initial acceptance and documentation of incoming waste, ensuring accurate tracking from the point of origin.

Waste measurement and storage: Facilities for weighing and categorizing waste prior to treatment, with secure and compliant storage to prevent contamination and accidents.

Waste treatment: A well-equipped area with appropriate technology for the effective and safe processing of various types of healthcare waste.

Washing of the transport packaging: An area dedicated to the cleaning and decontaminating of transport containers to ensure they are safe for reuse.

Storage area for cleaned transport equipment: An area to store cleaned transport equipment to ensure it remains uncontaminated until next use

Site office: An administrative area for managing operations, maintaining records, and coordinating waste management activities

Staff wash/changing area: Hygienic facilities for staff to change and wash, ensuring personal safety and reducing the risk of cross-contamination.

These comprehensive design elements ensure that both on-site and off-site treatment facilities can effectively manage healthcare waste while protecting public health and the environment.

Waste Treatment - Flow Diagram #5

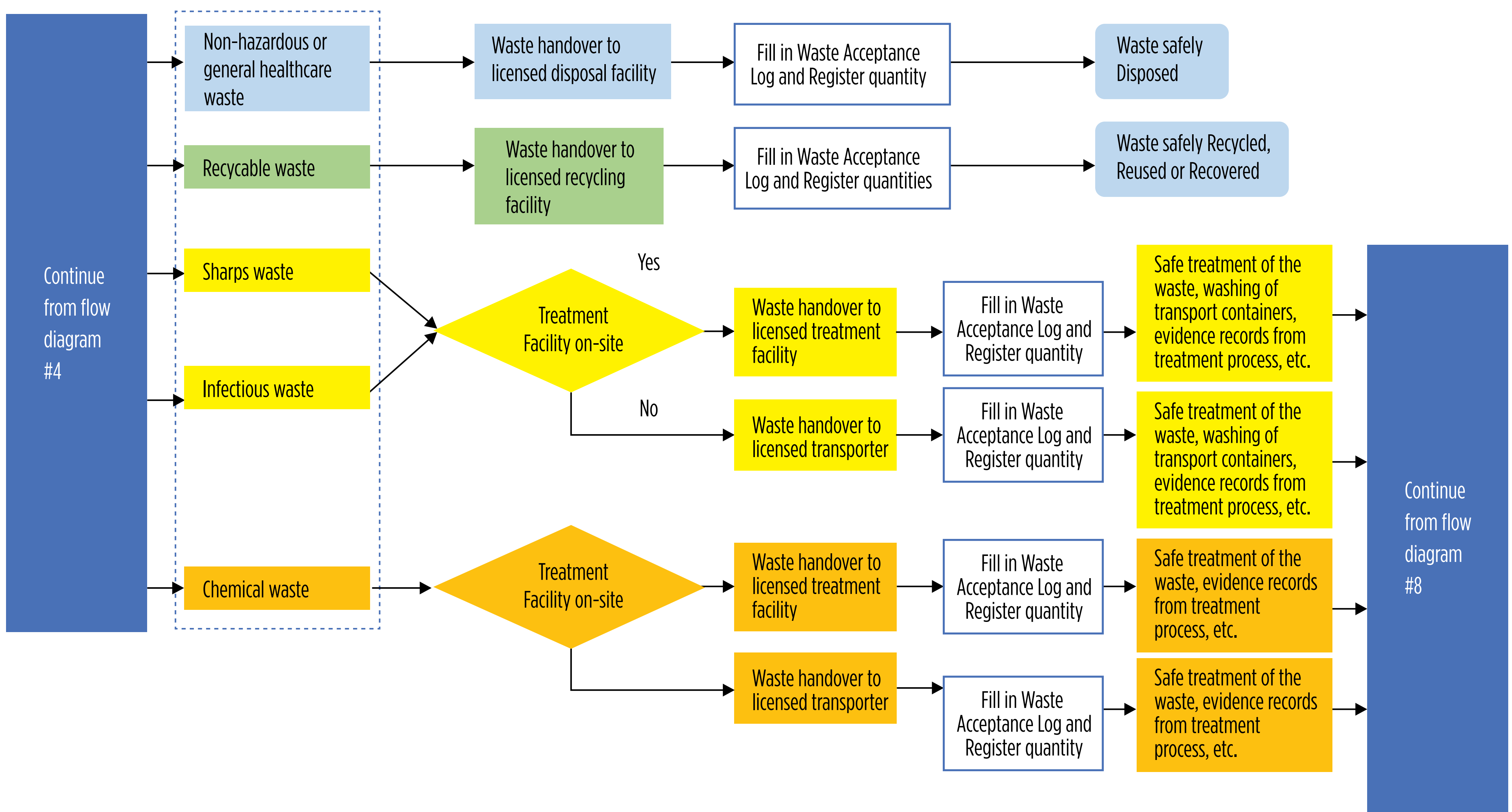


Figure 20 On-site or Off-site Waste Treatment models – Flow Diagram #5

7.3 Additional considerations:

When managing a treatment facility, the following requirements must also be considered to ensure efficient, safe, and continuous operation:

Staffing requirements:

A minimum of two operators should always be present at a treatment facility for safety reasons - a buddy system so that help can be summoned if an operator is injured.

Documentation availability:

All operating, maintenance, and service manuals for the equipment must be readily available at the treatment site.

Operator training:

Operators must receive comprehensive training to competently operate and maintain the treatment equipment. This training, provided by the equipment or technology supplier, should include:
Comprehensive training program: Covering basic maintenance, troubleshooting, service procedures, and validation of the treatment process, as well as specific training in emergency response actions.
Multi-department training: Involving workers from the service, health and safety, and quality control personnel to ensure a holistic understanding of the equipment and its operation.

Clear lines of communication:

Treatment plant operators must maintain clear lines of communication with management regarding service, maintenance, and the provision of secondary consumables to ensure that any operational issues are promptly addressed.

Supplier support and maintenance:

Preventive maintenance and service plan: The equipment supplier must provide a comprehensive plan, which includes national technical service support and a reliable supply of necessary spare parts and consumables during and beyond the equipment's warranty period.

Inspection services: The supplier must provide direct or contracted inspection services for the treatment equipment at least twice a year to identify and address potential issues early to ensure equipment longevity and reliability.

These considerations are essential to maintain high levels of operational efficiency, safety, and reliability.

7.4 Waste treatment technologies and equipment

Healthcare waste treatment technologies and equipment are critical components of healthcare waste management, ensuring that hazardous materials are safely disposed or reused, recovered, or recycled. Waste treatment involves the implementation of necessary measures (methods, activities, and technologies) to control (reduce or eliminate) all risks and contaminants in waste products that could harm human health and the environment. This can also include waste destruction processes such as shredding, milling, or incineration. Key technologies include autoclaving, incineration/ thermal treatment, chemical disinfection, and microwave treatment. Each of these technologies is further described and explained in the document.

Several factors need to be considered when selecting appropriate waste treatment technologies, including the type and volume of waste generated, available infrastructure, regulatory requirements, and environmental impact. The Stockholm Convention, on Persistent Organic Pollutants is a global treaty to protect human health and the environment from chemicals that persist in the environment for long periods of time, are geographically widespread, accumulate in the fatty tissues of humans, and wildlife, and have adverse effects on human health or the environment. Where applicable, the Basel Convention focuses on the reduction of hazardous waste generation and the promotion of environmentally sound management of hazardous wastes, the restriction of transboundary movements of hazardous wastes, and the application of a regulatory system for permissible movements of hazardous waste. The convention, to which many African countries are signatories, recommends the use of waste treatment technologies that minimize the formation and release of chemicals or hazardous emissions, and therefore these technologies should be prioritized, when countries select waste treatment technologies. The technologies and equipment selected must be reliable, easy to maintain, and appropriate to the local context, which in the African Region is often characterized by limited resources and infrastructure. For example, autoclaves and microwave ovens are preferred in settings with reliable electricity and water supplies, while incinerators may be more practical in areas where these utilities are less consistent. In addition, the implementation of these technologies should be supported by comprehensive training programs for operators, robust maintenance schedules, and consistent supply chains for spare parts and consumables. The use of international guidelines and best practices from organizations such as the UN, UNEP, WHO, CDC, and the International Solid Waste Association (ISWA) will help to ensure that the technologies selected not only meet global standards but also help to address the specific needs and challenges of healthcare waste management in the African region.

Another critical consideration when selecting a technology is microbial efficacy or the ability of a technology to achieve inactivation of microorganisms in the waste – making it safe to dispose of. There are several treatment standards / guidelines available, including but not limited to, the State and Territorial Association on Alternative Treatment Technologies (STAATT)[11] and the Environment Agency Guidance on Clinical Waste Treatment plants[12]. These references contain test procedures that are recommended to be applied to non-incineration treatment technologies in order to demonstrate their effectiveness upon installation of the equipment. In several jurisdictions, vendors have to demonstrate the effectiveness of the equipment and obtain regulatory approval before the technology is allowed to be placed on the market.

WHO emphasizes a hierarchical approach (Figure 21) to healthcare and laboratory waste management to minimize environmental and health impacts. This hierarchy prioritizes the prevention of waste generation, followed by the recovery of waste for secondary use where feasible and safe. For waste that cannot be recovered, the least harmful treatment or land disposal methods are recommended to mitigate health and environmental impacts. This approach is consistent with legal requirements in many countries, particularly for hazardous waste streams, and emphasizes the importance of using the most appropriate and least harmful treatment technologies available.

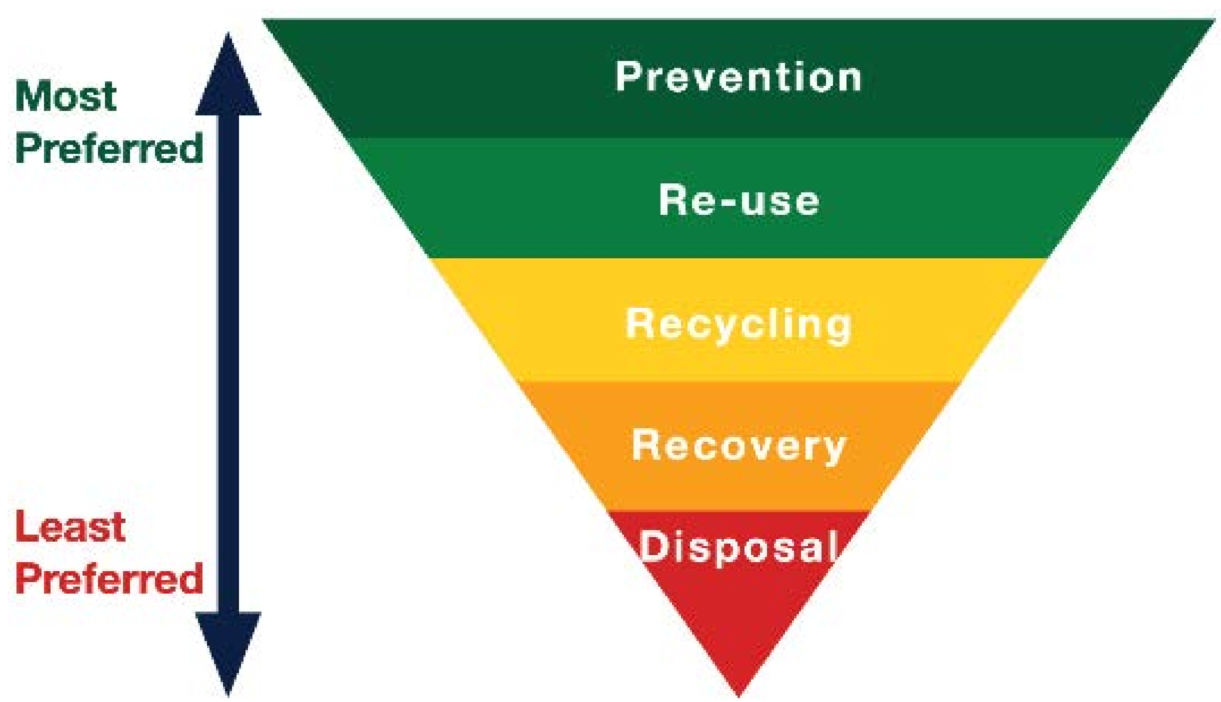


Figure 21 Waste management hierarchy

7.4.1 – Thermal Process Technologies

Thermal processes use high temperatures to either burn or sterilize waste materials. These processes can be broadly categorized into combustion (incineration) and non-combustion technologies (such as sterilization and integrated sterilization with shredding).

Incineration

Incineration is a high-temperature, dry oxidation process that reduces organic and combustible waste to inorganic, non-combustible matter (i.e., ash), significantly reducing the volume and weight of the waste. Typical temperatures range from 850°C in the primary chamber to over 1100°C in the secondary chamber. Incineration involves the chemical and physical decomposition of organic materials by combustion, pyrolysis, or gasification. This method is highly effective for treating most healthcare waste streams, including pathological waste. However, it has certain challenges and disadvantages (Table 6) that need to be managed to minimize the environmental impact.

Table 6 Advantages and disadvantages of the incineration process

Advantages	Disadvantages
Volume and weight reduction: Incineration can reduce waste volume by up to 90% and weight by up to 75%, significantly reducing the need for landfill space.	**Air pollution:** Incineration can release pollutants such as dioxins, furans, heavy metals, and particulate matter into the atmosphere, posing health risks and environmental concerns if not properly controlled.
Destruction of pathogens and toxins: High temperatures ensure the destruction of pathogens and hazardous organic compounds, making the waste safe for disposal.	**High costs:** Incinerators are expensive to build, operate, and maintain, requiring significant capital investment and ongoing operating costs.
Energy recovery: The heat generated during incineration can be used to produce steam, electricity, or heat, contributing to energy recovery, and reducing dependence on fossil fuels.	**Energy consumption:** Although energy recovery is possible, the incineration process itself is energy-intensive, potentially offsetting some of the energy gains.
Versatility: Incineration can handle a wide range of waste types, including medical, industrial, and municipal solid waste, making it a flexible waste management solution.	**Ash disposal:** The residual ash from incineration, which contains heavy metals and other toxins, must be safely disposed, often in specialized hazardous waste landfills, adding to waste management challenges.
Reduction of landfill usage: By significantly reducing the volume of waste, incineration reduces the pressure on landfill, sites and contributes to more sustainable management.	**Greenhouse gas emissions:** Incineration contributes to greenhouse gas emissions, such as carbon dioxide (CO_2), which can exacerbate climate change unless mitigated through carbon capture technologies.
Minimizing land contamination: By reducing the need for landfills, incineration also minimizes the risk of soil and groundwater contamination associated with landfill sites.	**Public opposition:** Incinerators facilities often face opposition from local communities due to concerns about health risks, environmental impacts, and the stigma associated with waste processing facilities.

7.4.1.1 - Incineration technologies

Incineration technologies can be categorized into several types, including rotary kiln incinerators, fixed hearth incinerators, fluidized bed incinerators, and controlled air incinerators. Each technology has specific applications, advantages, and limitations:

1. Fixed Hearth Incinerators

Fixed hearth incinerators are often used in smaller applications due to their simpler design and lower capacity. They are particularly suitable for smaller facilities, such as clinics and small hospital laboratories, where the volume of waste is low and less complex, as they are designed to incinerate infectious waste. Veterinary laboratories and rural or remote areas also benefit from fixed hearth incinerators due to their ease of operation and minimal infrastructure requirements. The main advantage of fixed hearth incinerators is their cost-effectiveness and ease of use making them more sustainable in resource-limited settings. Their lower operating and maintenance costs, combined with less complex technology, make them accessible and practical for sites with limited financial and technical resources. However, their limited flexibility in handling different types of waste, lack of pollution control systems and accessories and lower combustion efficiency compared to more advanced incineration technologies can be a drawback. (Figures 22, 23, 24, and 25)

2. Rotary Kiln Incinerators

Rotary kiln incinerators are versatile and highly effective for the treatment of a wide range of waste types, rendering them an optimal choice for the incineration of medical and healthcare waste, including infectious, pathological, and pharmaceutical waste. Their design enables the effective management and handling of materials with high moisture content and hazardous components, rendering an optimal choice for chemical waste and solvents. These incinerators operate at high temperatures, thereby ensuring the complete combustion of the waste and the destruction of harmful pathogens and toxic substances. Nevertheless, the complexity and high operational costs of rotary kiln incinerators represent notable limitations. As these incinerators are typically designed for continuous feed and high incineration capacities, they necessitate a considerable investment in infrastructure and maintenance, rendering them less suitable for resource-limited settings where financial and technical resources may be constrained. The implementation of sustainable solutions in such settings necessitates substantial external support and investment (Figure 26).

Table 7 Advantages and Disadvantages of Incineration Technologies

Technology	Advantages	Disadvantages
Fixed Hearth Incinerators	Simple design, lower initial cost	Limited waste handling capacity, less efficient combustion
Rotary Kiln Incinerators	Versatile, can manage various waste types, efficient heat transfer	High capital and operational costs, complex maintenance

7.4.1.2 - Emission Control and Environmental Impact

The incineration process generates a number of combustion by-products, including gaseous emissions such as steam, carbon dioxide, nitrogen oxides, and various volatile substances (e.g., metals, halogenic acids, and products of incomplete combustion). In addition, particulate matter, and solid residues in the form of ash are produced. In order to mitigate the environmental impact of these emissions, it is necessary to implement advanced emission control systems. Examples of such systems include:

- **Scrubbers:** Remove acidic gases and other pollutants.
- **Baghouse Filters:** Capture fine particulate matter.

- **Electrostatic Precipitators (ESP):** Remove particulate matter from flue gases.
- **Selective Catalytic Reduction (SCR):** Reduce nitrogen oxide emissions.

Additional waste segregation considerations

Pre-treatment

The basic principle of effective wastewater management is the imposition of absolute prohibition on the discharge of hazardous liquids into sewer systems. Pretreatment is recommended for wastewater streams from departments such as medical laboratories. Such pretreatment may entail acid–base neutralization, filtration to remove sediments, or autoclaving of samples from patients with highly infectious diseases.[14]

The incineration process does not necessitate any preliminary treatment, if the following waste types either are excluded entirely or are kept to an absolute minimum:

- Pressurized gas containers;
- Large amounts of reactive chemical waste;
- Silver salts and photographic or radiographic wastes;
- Halogenated materials such as polyvinyl chloride (PVC) plastics (waste and packaging of waste should not contain PVC material);
- Waste containing mercury, cadmium, and other heavy metals, such as broken thermometers, used batteries and lead-lined wooden panels;
- Sealed ampoules or vials that may explode or rupture during the combustion process;
- Radioactive materials;
- Pharmaceuticals thermally stable in conditions below 1200 °C (e.g. 5-fluorouracil);
- Non-combustible liquid waste in large containers (ex. Plastic lab bottle/jug/carboy containing guanidine thiocyanate contaminated waste)

Incineration represents an effective strategy for reducing waste volume and neutralizing hazardous materials. However, it is not without its drawbacks. It is imperative that effective management and mitigation strategies be employed in order to address the environmental and health impacts associated with this process. By weighing the advantages and disadvantages, stakeholders can make informed decisions regarding the use of incineration as part of an integrated waste management strategy.

Photos of various incineration technologies currently in operation across Africa

Figure 22 Fixed hearth incinerator – SA Incinerator

Figure 23 Fixed hearth incinerator – Inciner8

Figure 24 Fixed hearth incinerator – Incinco.

Figure 25 Fixed hearth incinerator - Addfield

Figure 26 Rotary kiln incinerator

7.4.2 - Non-burn thermal processes

Non-burn thermal processes, such as sterilization and integrated sterilization with shredding, represent an alternative method for the treatment of healthcare waste. These technologies employ low temperatures without combustion to sterilize waste, thereby reducing harmful emissions and environmental impact in comparison to incineration.

7.4.2.1 - Autoclaving

Autoclaving is a widely utilized non-burn thermal process that employs pressurized steam to eliminate pathogens. This method is effective for a variety of infectious waste, including sharps, dressings, and surgical instruments. The temperature and pressure conditions within the autoclave ensure the complete elimination of pathogens, rendering the waste safe for disposal or further processing. The advantages of autoclaving include low operational costs, ease of use, and the absence of harmful emissions typically associated with incineration. However, its effectiveness is limited when dealing with pathological, chemical, or pharmaceutical waste, which may require different treatment to neutralize hazardous components (Figures 27, 28, 29, 30, and 31).

Integrated Sterilization with Shredding

Integrated systems that combine sterilization with shredding represent an advanced approach to healthcare waste management. In these systems, the waste is first subjected to a shredding process, which serves to reduce its volume while simultaneously increasing the surface area exposed to the heat. This shredding step not only enhances the efficiency of the subsequent sterilization process but also renders the waste unrecognizable, thereby addressing privacy and regulatory concerns. Subsequently, the waste undergoes thermal treatment, typically utilising steam, or dry heat, with the objective of achieving complete sterilisation. The integration of shredding and sterilization results in a more compact and manageable waste product, which can be safely disposed of in standard landfills or used as secondary raw material in other processes. These systems are particularly effective for the management of infectious waste. However, as with autoclaving, they are less suitable for the disposal of pathological or pharmaceutical waste that may contain substances resistant to thermal treatment.

Table 8 Advantages and limitations of sterilizers and shredders

Advantages	Limitations
Autoclaving:	
Low operational costs	Less effective for pathological, chemical, and pharmaceutical waste
Ease of use	May require higher temperatures for some waste types
No harmful emissions	
Integrated Sterilization with Shredding:	
Reduces waste volume and enhances sterilization	High initial setup costs
Makes waste unrecognizable, addressing privacy concerns	Ongoing maintenance and operational requirements
Produces a compact, manageable waste product	
General Advantages of Non-burn Thermal Processes:	
Significantly reduce harmful emissions and environmental impact	Limited effectiveness for certain types of waste
Effective for most infectious waste	

7.4.2.2. Microwave based Technology

Microwave treatment is essentially a steam-based process, as treatment occurs through the action of moist heat and steam generated by microwave energy. The water present within the waste is rapidly heated by microwave energy at a frequency of approximately 2450 MHz and a wavelength of 12.24 cm. In general, microwave treatment systems consist of a treatment area or chamber into which microwave energy is directed from a microwave generator where the waste is heated up to a temperature of up to 100 °C. The altitude of the location where the microwave is used may have an impact on the performance of the microwave system. At higher altitudes, the reduction in pressure may necessitate a longer heating time to reach 100 °C resulting in a longer overall treatment duration. Following the treatment process, the waste is classified as non-hazardous waste and may be disposed of in accordance with standard protocols (Figures 32, 33, and 34)[13]

Table 8 Advantages and limitations of sterilizers and shredders

Advantages	**Limitations**
Microwave:	
Low environmental impacts	Reliable solid waste collection required
Residue is unrecognizable	Reliable electricity connection needed
Residue is non-hazardous	Higher costs and maintenance (internal moving parts) (continuous type)
Reduction of the waste volume	Waste needs a minimum humidity, or water needs to be added
Complies with the Stockholm Convention	Special waste bins are needed (Batch type)

7.4.2.3. Frictional heat treatment[15]

Additionally, frictional heat can be used to destroy healthcare waste. The technology is based on the generation of heat through the friction and impact of the waste by rotor blades, with the addition of resistance heaters to facilitate temperature adjustment when necessary. The waste is subjected to temperatures of up to 150°C, accompanied by a shredding process that renders the material unrecognizable. The requisite heat is provided by heaters or generated by a rotor operating at high speeds (typically 1000 to 2000 rpm). A moist environment is kept inside the chamber by means of negative pressure (see Figure 35).

The waste is subjected to a decontamination process whereby it is maintained at temperatures between 135°C and 150°C for several minutes. The generation of vapour is facilitated by the utilization of heat exchangers, which facilitate the condensation of the water. Subsequently, the waste is conveyed to a filter group comprising activated carbon and HEPA filters after which it is released into the environment. The utilization of frictional heat treatment is associated with several advantages and disadvantages,

Table 10 -Advantages and limitations of Frictional heat treatment

Advantages	Disadvantages
Frictional heat treatment	
Low environmental impacts	Reliable electricity connection needed
Residue is non-hazardous	Higher maintenance (internal moving parts)
Reduction of the waste volume	
Residue is unrecognizable	
Complies with the Stockholm Convention	

Photos - Autoclaves and other non-burn technologies

Figure 27 Medi-Clave – static autoclave – 260 liters

Figure 28 Medi-Clave – static autoclave -7,000 Liters

Figure 29 Bondtech static autoclave

Figure 30 Ecodas hybrid autoclave (Integrated shredder)

Figure 31 Tesalys autoclave (Integrated shredder)

Figure 32 Ecosteryl microwave technology

Figure 33 Bertin microwave technology

Figure 34 Bertin microwave technology

Figure 35 Newster friction technology

7.4.3 - Validation of waste treatment technologies

The validation of waste treatment technologies is a crucial step in ensuring that these systems are capable of effectively and reliably managing and mitigating hazardous waste, thereby safeguarding human health and the environment. This process involves a comprehensive evaluation of the various technologies to confirm their performance, safety, and compliance with regulatory standards. It is recommended that validation be conducted at least annually for Incinerators and quarterly for non-burn technologies following the completion of commissioning tests.

Key Aspects of Validation:

1. **Performance Evaluation:** The objective of the validation process is to assess the efficiency of waste treatment technologies in achieving the desired outcomes, such as the reduction of hazardous substances to acceptable levels. This includes subjecting the technology to a series of tests under varying conditions with the objective of guaranteeing its consistent compliance with the established performance criteria.

2. **Safety and Compliance:** Technologies must undergo a rigorous validation process to ascertain their safety and compliance with relevant environmental and health regulations. This includes ensuring that the technology does not produce harmful by-products or emissions and that it adheres to standards prescribed by regulatory bodies.

3. **Operational Testing:** The technology is subjected to rigorous testing to ensure its functionality and reliability over time. This includes an assessment of the capacity to handle varying types and quantities of waste as well as an evaluation of its performance under different operational conditions.

4. **Documentation and Reporting:** It is vital to have comprehensive documentation of the validation process. This includes recording the testing procedures,

results, and any deviations observed. Comprehensive reporting ensures transparency and provides a basis for regulatory approval and future reference.

5. **Training and Capacity Building:** Validation also involves training personnel to operate and maintain the technology effectively. It is essential that operators have a good understanding of the technology and its requirements to ensure successful waste management.

6. **Continuous Monitoring and Improvement:** Post-validation, ongoing monitoring is necessary to ensure the technology continues to perform as expected. Based on the results of this monitoring, regular maintenance and updates may be required.

Table 11 below summarizes validation tests for some technologies*

Table 11 Validation test for various technologies

Technology	Parameters	Minimum Standards
Incineration	Operating temperatures Gaseous emissions	8000 C Primary Chamber & 12000c in secondary chamber Test for NO, SOX, NO2, CO, PCDD/ PCDF in line with country acceptable limits.
Autoclaving	Temperatures Biological inactivation levels Steam distribution and challenge tests	1210C- 1500C (Depending on equipment manufacturer) >Log 4 Inactivation (Depending on manufacturer's guidance) and regulatory requirements Process Challenge Tests
Microwaving	Temperatures Biological inactivation levels	1000C (Depending on equipment manufacturer guidance) >Log 4 Inactivation (Depending on manufacturer's guidance)

*Several countries have developed standards for validation and challenge (periodic quality tests) that need to be conducted on all technologies (burn and non-burn technologies).[16]

CASE STUDY 1:

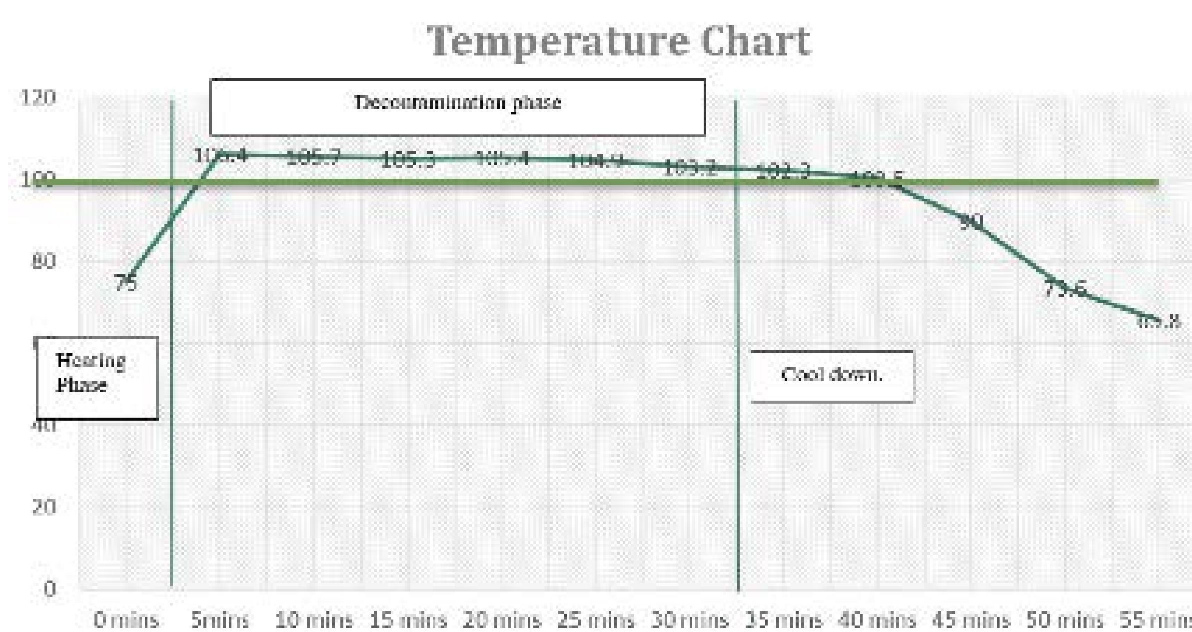
OUTSPAN HOSPITAL, NYERI COUNTY, KENYA– NON-BURN TECHNOLOGY: MICROWAVING

Introduction

Outspan Hospital is a Level 5 Teaching and Referral Hospital located in Nyeri County in the central region of Kenya. The hospital has a 250-bed capacity, the hospital enabling it to serve up to 300 patients per day. The hospital generates between 20 and 30 kilograms of infectious waste on a daily basis. In 2020, Outspan Hospital installed the Microwave system to address its waste management needs. This cutting-edge technology was selected for its effectiveness in disinfecting and converting a range of biomedical waste (solids, liquids, glass, sharps, blades, and more.) into inert dry municipal waste on-site.

Microwave System Features Grinding Mechanism:

The system incorporates a grinder that reduces glass waste into a fine powder and sharps/blade material into tiny particles of less than 2mm in size. The sterilization process is as follows: The ground waste is then subjected to a microwave treatment at 1000C for 30 minutes, which effectively sterilizes it. System capacity: The system was designed to treat up to 20 kilograms of medical waste per hour.



Validation Results

The successful validation confirmed that the Sterilwave system is capable of effectively decontaminating biomedical waste, thereby ensuring safety and compliance with health standards. The installation of the Microwave's healthcare waste treatment technology at Outspan Hospital has significantly improved the management of biomedical waste. This technology not only ensures the safe disposal of hazardous materials but also aligns with environmental standards, making it a valuable addition to the hospital's operations.

Challenges with Technology

One of the most significant concerns is the cost of running the equipment, with daily electricity consumption expenses ranging from USD 25-30. This operational cost is further increased by the necessity to purchase biological indicators for validation, which adds USD $550 per kit. The financial burden is exacerbated by the unavailability of spare parts and test kits locally. This scarcity hinders the timely maintenance and repair of the equipment, which in turn affects the overall efficiency and reliability of operations.

7.4.3 Chemical treatment technologies

As the name suggests, chemical-based treatment technologies utilize chemicals such as sodium hypochlorite or peracetic acid (see Envetec technology (Figure 36) to treat waste. The healthcare waste must first be destroyed, typically in a sealed chamber that allows for shredding or maceration of the waste. Once the specified contact time has elapsed, the solids will be separated from the liquid effluent.

Following the post treatment process, the liquid would be discharged to the sewer system while the solids would be disposed of at a landfill site. Furthermore, chemical treatment systems can also be utilized for the management of chemical wastes. One such example is the Newster PURA system (Figure 37) which is designed to treat infectious liquid waste as well as liquid chemical waste.

Additionally, UV light and hydrogen peroxide can also be used to treat liquid waste containing guanidine thiocyanate, which is generated from viral load testing platforms.

For further information, please visit the Enviolet website at link below: https://www.enviolet.com/en/home.html

Table 12 Advantages and limitations of Chemical treatment Technologies (chemical depended)[17]

Advantages	Disadvantages
Chemical Treatment Technologies	
Low environmental impact	Real time monitoring of chemical concentration is difficult
No hazardous residues	Strict occupational safety measures are necessary
Reduction of the waste volume	Higher costs and maintenance (internal moving parts)
Residue is unrecognizable	
Complies with the Stockholm Convention	

Figure 36 Envetec Generations technology

Figure 37 Newster PURA chemical waste treatment system

Alternative technologies (tissue digester and solvent recovery / recycling)

Figure 38 Tissue digestor (Envirogest)

Tissue digestors are now a standard tool for the management of a wide range of anatomical waste such as organs/ soft tissue, placentas, and animals used in research. Potassium or sodium hydroxide are used to dissolve tissue (Figure 38).

It would be prudent to consider implementing solvent recovery and recycling systems in histology laboratories that utilize spent solvents such as alcohols, xylene and formaldehyde. (Figure 39)

Wheeled solvent recovery

Formalin recovery

Figure 39 Solvent recovery / recycling systems CBG

7.4.4 Criteria for the selection of waste treatment technologies

The selection of waste treatment technologies is a complex process, particularly in low- and middle-income countries (LMICs). A multitude of factors must be considered, including the type and volume of waste, the availability of infrastructure, regulatory requirements, and environmental considerations. It is essential to adapt these technologies to the specific contexts, infrastructure, and resource limitations prevalent in these regions.

The following provides a guide for selecting appropriate laboratory waste treatment technologies that align with specific needs and constraints.

1. **Assessment of Waste Types and Volumes:**

- **Identify Waste Types:** It is important to categorize the types of laboratory waste generated to ensure effective management and compliance with regulations. This includes infectious waste (e.g., used swabs, sample tubes, pipettes, used PPE), pathological waste (e.g., tissue samples, blood), pharmaceutical waste (e.g., expired medications, if any), sharps (e.g., needles, scalpels, lancets, glass slides and various glassware), and chemical waste (e.g., reagents, solvents, expired and discarded chemicals). The correct treatment method must be applied for each type.
- **Volume Estimation:** Measure the daily and monthly volume of each type of waste generated. This data is crucial for determining the capacity requirements for the treatment technology and planning for waste segregation and storage.

2. **Regulatory and Environmental Compliance:**

- **Regulatory Standards:** It is the responsibility of the selected technology provider to ensure that their product complies with all relevant national and international regulatory standards for laboratory waste management. This includes regulations on waste collection, transportation, treatment, and disposal of waste.
- **Environmental Impact:** It is recommended that an environmental impact assessment be conducted, with a particular focus on emissions (e.g., air pollutants from incineration), residues (e.g., ash or sludge), and potential contamination (e.g., groundwater contamination from leachate). Select technologies that minimize negative environmental impacts and align with sustainability goals.

3. **Infrastructure and Utility Requirements:**

- **Utility Availability:** It is essential to evaluate the availability and reliability of essential utilities such as electricity, water, and fuel. It may not be viable to implement certain technologies that require a continuous power supply in areas where power outages are a regular occurrence.
- **Space Requirements:** It is essential to ascertain the physical space required for the installation and operation of the technology. It is important to consider factors such as accessibility for waste transport vehicles, proximity to waste generation points, and room for future expansion when determining the physical space required for the installation and operation of the technology.

4. **Financial Considerations:**

- **Initial Investment:** It is important to provide an analysis of the capital expenditure required for purchasing and installing the technology. This includes costs associated with the procurement of equipment, site preparation, and any necessary infrastructure upgrades.
- **Operational Costs:** Estimation of the ongoing expenses, including labour, utilities, maintenance, and consumables is an essential step. It is important to understand the total cost of ownership to create a robust budget and financial plan.
- **Funding Sources:** It is advisable to explore a range of potential financing options such as government funding, international grants, loans, and public-private partnerships. It is essential to identify sustainable funding sources to guarantee the long-term viability of the waste treatment system.

5. **Technical Feasibility and Reliability:**

- **Technical Complexity:** Assess the complexity of operating the technology. Simpler technologies may be more suitable for resource-limited settings where highly trained personnel may be scarce. It would be prudent to consider the possibility of centralising the waste treatment operation.

- **Performance Reliability:** Evaluate the reliability of the technology to manage the specific types and volumes of waste generated. Review performance data and case studies from similar environments to assess effectiveness.
- **Integration Ease:** It is important to consider how easily modern technology can be integrated into existing waste management systems. The implementation of technologies that complement current practices can be achieved with greater ease and with less disruption to existing systems.

6. Human Resource Capacity:

- **Technical Expertise:** It is important to ascertain the level of technical expertise that will be required to operate and maintain the technology. It is important to identify any gaps in the current staff skill set of the workforce and to plan for the necessary training programs to bridge these gaps. It is essential to require comprehensive training for operation, service, and maintenance from vendors of the equipment or technology.
- **Training Needs:** It is essential to develop and implement training initiatives to build the capacity of personnel. Ongoing training is key to ensuring that staff can manage the technology effectively and adapt to any updates or changes.
- **Capacity Building:** It is recommended that long-term capacity-building initiatives be invested in to create a pool of skilled professionals who can support the waste management system, technology operation, and maintenance, thus ensuring sustainability.

7. Maintenance and Support:

- **Spare Parts Availability:** It is essential to ensure that spare parts and consumables at the local or regional level to minimise downtime. It is essential to establish a reliable supply chain for essential components.
- **Technical Support:** Access to technical support services is critical for the completion of routine maintenance tasks and the resolution of any technical issues that may arise. It is important to evaluate the availability and responsiveness of support from the technology provider.
- **Maintenance Planning:** It is essential to develop a comprehensive maintenance schedule and budget for routine checks, preventive maintenance, and emergency repairs. Regular maintenance is the key to ensuring that the technology operates efficiently and extends its lifespan.

8. Health and Safety:

- **Safety Standards:** It is essential to guarantee that the technology complies with the requisite health and safety standards for both operators and the surrounding community. Furthermore, it is vital to implement measures to safeguard staff from exposure to hazardous waste and emissions.
- **Protective Equipment:** It is the responsibility of management to provide adequate personal protective equipment (PPE) and to ensure that all employees receive the necessary training on its proper use. It is essential to implement safety protocols to prevent accidents and ensure a safe working environment.
- **Emergency Preparedness:** Establish emergency response procedures for potential accidents or equipment failures. Regular drills and training can help staff respond effectively to emergencies.

9. Community and Stakeholder Engagement:

- **Stakeholder involvement:** Involve local communities and stakeholders throughout the selection and implementation process. Involving stakeholders helps to address concerns, build trust, and ensure that the technology meets the needs of the community.
- **Transparency:** Maintain transparency about the benefits and risks associated with the chosen technology. Open communication encourages public support and cooperation.
- **Awareness programs:** Develop public awareness programs to educate the community about the importance of proper waste

management and the role of modern technology. Informed communities are more likely to support and participate in waste management initiatives.

10. **Sustainability and Scalability:**

- o **Long-term sustainability:** Consider the long-term sustainability of the technology, including its environmental and economic impacts. Technologies that are environmentally friendly and cost-effective over time are preferable.
- o **Scalability:** Evaluate the potential for scaling up the technology to meet future waste management needs. Technologies that can be easily expanded or upgraded can adapt to growing or changing waste streams.
- o **Continuous improvement:** Plan for continuous improvement and adaptation to new waste management challenges. Staying up to date with advancements in waste management technologies ensures that the system remains effective and efficient.

The above criteria will help decision-makers to make informed choices about selecting and implementing the most appropriate laboratory waste management technologies for their countries and facilities. This can ensure that waste management systems are not only effective but also sustainable, considering the specific context, infrastructure, and resource limitations of each country. Countries can also use international guidelines and resources from organizations such as the United Nations, World Health Organization, and International Solid Waste Association to implement and operate effective healthcare waste management technologies.[18] Additional references on waste treatment technologies can be found in "Compendium of Technologies for Treatment / Destruction of Healthcare Waste (UNEP 2012)19,20 Medical Waste Treatment Technologies: Evaluating Non-Incineration Alternatives A Tool for Health Care Staff and Concerned Community Members – Health Care Without Harm, 2002[21]

7.5 Commissioning of laboratory waste treatment facilities

Commissioning of healthcare waste treatment facilities
The commissioning of healthcare waste treatment facilities represents a critical and comprehensive process that ensures the safe, efficient, and compliant operation of waste treatment systems. A comprehensive commissioning process offers a number of advantages. Such a process enhances compliance by ensuring that the facility meets all local, national, and international standards[22] and regulations, thereby reducing the risk of legal and environmental issues. The process also enhances safety, as it verifies that all equipment is installed and operated in a safe manner, thereby protecting both the facility staff and the environment.

The operational efficiency of the facility is confirmed as the equipment operates within optimal parameters to support the overall efficiency of the waste treatment process. Additionally, comprehensive documentation and traceability are provided, supporting future audits, maintenance, and troubleshooting efforts, and a clear record of compliance and operational history.

Key Stages of the Commissioning Process

The commissioning process can be divided into three key stages: Installation Qualification (IQ), Operational Qualification (OQ), and Performance Qualification (PQ).[23]

a. Installation Qualification (IQ)

The objective of the IQ process is to guarantee that all equipment, sub-systems, and auxiliary systems have been installed and configured in accordance with the manufacturer's specifications or installation checklist.

Key Activities:

- **Physical Verification:** It is essential to guarantee that all components of the equipment are installed correctly and securely. This entails confirming that all fittings' connections and safety features are professionally installed.

- **Specification Compliance:** The installation must be checked to ensure that it aligns with the manufacturer's specifications and installation checklists. Any deviations must be approved, documented, and rectified with the manufacturer.
- **Utility Connections:** It is essential to guarantee that all necessary utilities (electricity, water, ventilation, etc.) are correctly connected and operational. This entails verifying power supply specifications, water pressure levels, and airflow rates.
- **Documentation:** It is essential to record all installation procedures, equipment serial numbers, and any deviations or modifications made during the installation process. This documentation is crucial for future reference and compliance audits.

b. Operational Qualification (OQ)

The OQ process serves to confirm that the equipment operates consistently within the user requirement specifications and within the manufacturer-specified operating ranges.

Key Activities:

- **Operational Testing:** The objective is to conduct tests to ensure that all operational controls, alarms, and interlocks are functioning correctly. This entails verifying the start-up and shutdown sequences, emergency stop functions, and system alarms.
- **Performance Verification:** The equipment is evaluated under normal and stress conditions to ensure that it operates within the specified process parameters. This entails verifying the temperature ranges, pressure levels, and processing times.
- **Data Recording:** The collection and analysis of data allows to demonstrate consistent operation. This data helps to identify any potential issues and ensure that the equipment meets operational expectations. The data collected from the processes represents evidence that the waste has been treated properly.
- **SOP Validation:** It is essential to guarantee that all standard operating procedures (SOPs) are in place, validated, and understood by the operating personnel. This includes providing staff with comprehensive training on the correct operation and maintenance of equipment.

c. Performance Qualification (PQ)

PQ provides verification that the system performs as expected under simulated real-world conditions, ensuring it meets the performance criteria defined in the user requirement specifications or functional requirements specifications. PQ is also known as validation tests, and is a vital part of the process, for both during initial commissioning and for ongoing quality control.

Key Activities:

- **Real-World Simulation:** The tests are conducted in a manner that simulates the actual operating conditions of the facility, including processing the types of waste that the facility will manage. This guarantees that the equipment is capable of managing the anticipated waste loads and characteristics.
- **Emission Testing:** Ensuring that emission levels comply with regulatory standards. This entails measuring the release of gases, particulates, and other pollutants to guarantee that they fall within permitted limits.
- **Waste Treatment Efficiency:** Assessing the effectiveness of the waste treatment process. This entails verifying the complete destruction of pathogens and hazardous materials, as well as the reduction of waste volume and weight.
- **Validation Tools and Indicators:** The utilization of various appropriate validation tools and indicators allows to confirm that process requirement parameters have been achieved. For example, waste sterilization processes often employ biological indicators or spore tests to assess the sterilization directly by killing highly resistant microorganisms (e.g., Geobacillus stearothermophilus). Additionally, rapid Level IV chemical indicators are used to confirm that materials have been exposed to the required temperature and time for sufficient microbial inactivation.

- **Periodic Challenge Testing:** The same tests used during the commissioning phase can be applied on a periodic basis to ensure ongoing compliance with operational parameters and emissions standards. This process confirms that the facility continues to operate without any negative impacts on human or environmental health. These tests are mandatory after each service or maintenance of equipment.
- **Documentation:** It is essential to record all test results, observations, and any corrective actions taken. This documentation is crucial for demonstrating compliance and for future operational reference.

Advantages of a Comprehensive Commissioning Process

- **Enhanced compliance:** Ensures that the facility complies with all local, national, and international standards and regulations, thereby reducing the risk of legal and environmental issues.
- **Improved safety:** Ensures that all equipment is installed and operated in a safe manner, protecting both the facility staff and the environment.
- **Operational efficiency:** Ensures that the equipment operates within optimal parameters, thereby improving the overall efficiency of the waste treatment process.
- **Risk mitigation:** Identifies and addresses potential issues at any early stage in the commissioning process, thereby reducing the likelihood of future operational problems.
- **Documentation and Traceability:** Provides comprehensive documentation that supports future audits, maintenance, and troubleshooting efforts, ensuring a clear record of compliance and operational history.

It is essential to guarantee that all is operational from the outset to avoid the potential costs and disruptions associated with repairs and operational downtime. This can be challenging where resources are limited. Furthermore, adherence to best practices and international standards during commissioning helps to enhance the overall quality and reliability of waste treatment operations, thereby contributing to sustainable healthcare and environmental protection. Regular periodic challenge testing using the same validation tests employed during commissioning ensures ongoing compliance and operational excellence, reinforcing the facility’s commitment to safety and sustainability. Please refer to Figures 40 and 41 for the operational diagrams of the waste treatment facilities.

Waste Treatment facility operations No Burn Technologies - Flow Diagram #6

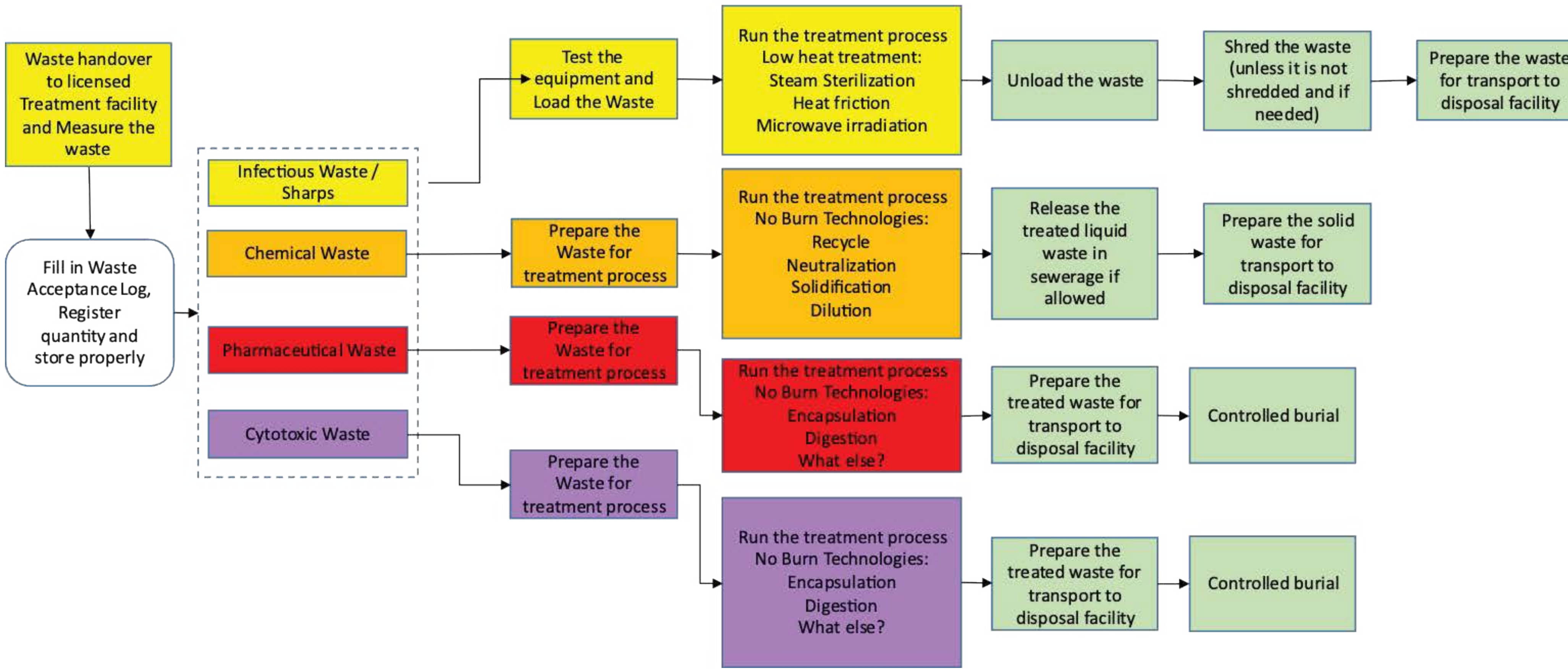


Figure 40. Non-burn technologies Flow Diagram 6

Waste Treatment facility operations Incineration Technologies - Flow Diagram #7

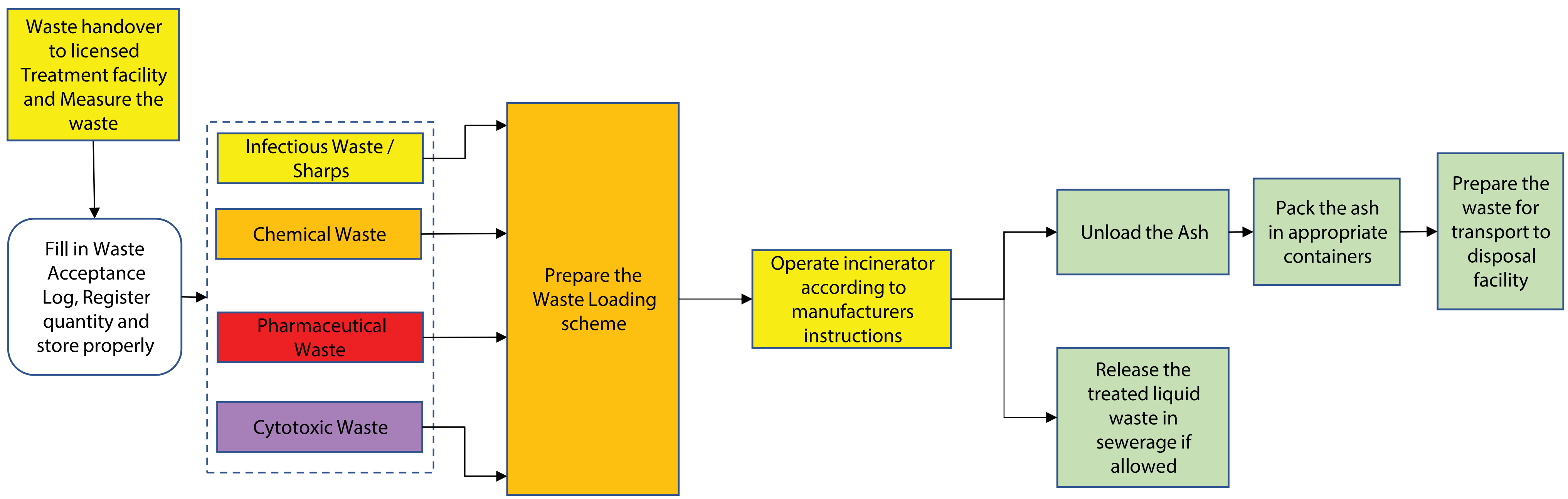


Figure 41 Incineration technologies -Flow Diagram #7

7.6 - DISPOSAL

The disposal phase represents the final and critical step in the healthcare waste management process. It is essential to ensure that the by-products from the waste treatment process are disposed of in a manner that does not pose a threat to public health or the environment.

Incineration is a common method for the disposal of healthcare waste, resulting in the generation of bottom ash and fly ash as by-products. Glass vials as well as metal objects can remain intact after being processed in an incinerator (Figure 42). These ashes are toxic, and often contain heavy metals such as lead and mercury. It is of the utmost importance that these residues are disposed of correctly. This is typically achieved through landfilling or burial in designated ash pits. Careful handling and management of these ashes prevent environmental contamination and safeguard public health.

Figure 42 Bottom ash from incinerator (Note intact medication vials)

Non-burn technologies, such as autoclaving, microwaving, and chemical disinfection, are highly effective at neutralizing pathogens and hazardous materials without generating toxic ash. However, the treated waste still requires proper disposal, usually through landfilling. Un-shredded or shredded waste from non-burn technologies must be managed with the same level of care as incinerated waste to prevent any residual contamination from entering the environment. This ensures that non-burn technologies remain a safe and effective disposal option (Figures 43 -46).

Photos of sterilized waste

Figure 43 Medi-Clave autoclaved waste

Figure 44 Ecosteryl microwave shredded waste

Figure 45 Tesalys autoclave processed waste

Figure 46 Bertin microwave processed waste

While chemical disinfection is an effective method, it can result in the release of chemical substances into the environment if not neutralized before disposal. To avoid this, it is essential to assess the characteristics of the effluent and solid residue to determine the appropriate disposal route. Local/national environmental guidelines and regulations should be reviewed for the handling, storage, and disposal of used chemical disinfectants to prevent contamination.

7.6.1 - GENERAL SPECIFICATIONS FOR ASH PITS AND LANDFILL

Ash Pits for Small-Scale Medical Waste Incineration

Ash pits represent an effective solution for the disposal of waste from small-scale medical waste incineration. The design and construction of these pits must prevent uncontrolled disposal and environmental contamination. It is imperative that the pits be lined and covered to prevent the leaching of ash, which can contain hazardous substances, into the soil and groundwater.

The ash often contains heavy metals and other toxic compounds, thereby necessitating careful management. The key design features are as follows:

1. **Location:** Ash pits should be situated away from water sources, flood plains, and residential areas to prevent contamination and exposure.
2. **Lining:** The pit should be lined with impermeable materials like clay or synthetic liners to prevent leachate from entering the soil and groundwater.
3. **Covering:** Following each deposition, the ash should be covered with a layer of soil to reduce exposure to wind and water, and to minimize leaching and erosion.
4. **Size and depth:** The size and depth of the pit should be sufficient to accommodate the anticipated volume of ash, with provision for future expansion or the use of multiple pits if necessary.
5. **Ventilation and drainage:** Adequate ventilation must be provided to prevent the accumulation of gases, and drainage systems should be installed to manage rainwater infiltration.

Landfills for Solid Waste

For the disposal of large quantities of hazardous waste, the use of properly engineered landfills is recommended. Such landfills should be contrasted with multiple protective layers, including a bottom liner, a leachate collection system, and a cover to minimize the escape of contaminants. The specifications are as follows:

1. **Liner systems:** It is recommended that a composite liner system consisting of a high-density polyethylene (HDPE) liner and a compacted clay layer be employed to prevent leachate migration.
2. **Leachate collection:** It is essential to implement an efficient leachate collection and treatment system to ensure the collection and treatment of any liquids that may leach out of the waste. This system should include a network of perforated pipes and collection sumps.
3. **Cover Systems:** It is recommended that daily and final cover systems be employed to minimize exposure to the environment. The final cover often includes a barrier layer to prevent water infiltration and a vegetative layer to prevent erosion.
4. **Gas Management:** It is imperative that systems be installed to capture and manage landfill gas (methane and carbon dioxide) to prevent greenhouse gas emissions and explosions.
5. **Monitoring Systems:** It is recommended that groundwater monitoring wells should be installed around the landfill to detect any potential contamination. It is essential that regular monitoring of groundwater, surface water, and gas emissions be conducted to ensure that the landfill does not have a negative impact on the surrounding environment.

Concerning hazardous waste, the Basel Convention and other international regulatory frameworks provide frameworks for the safe disposal of such waste, including incineration ash (Figure 47).

Disposal of Residues from Treatment Process - Flow Diagram #8

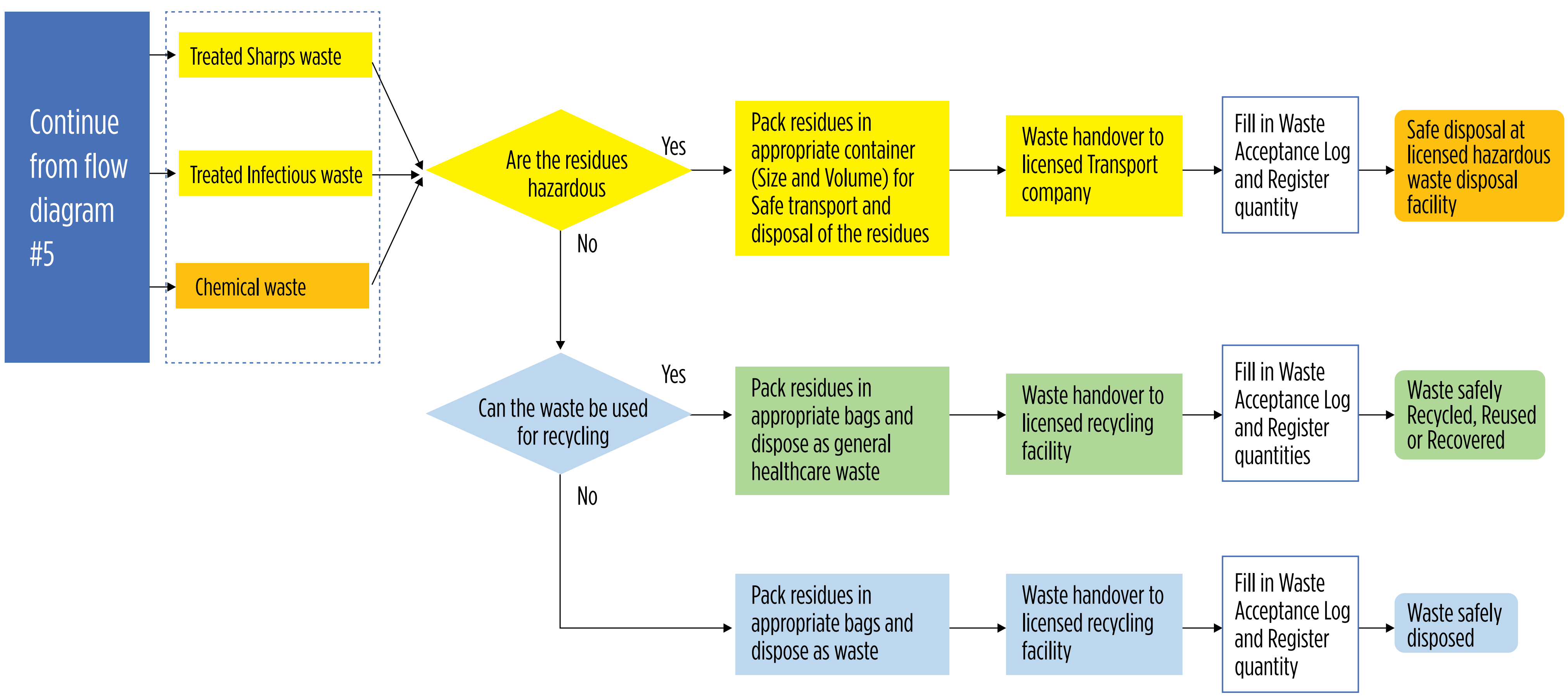


Figure 47 Disposal of Residues from Treatment Process - Flow Diagram #8

8. Strengthening National Laboratory Waste Management Capacities

Based on the experiences gained from the implementation of the HIV VL/EID program and the establishment of the laboratories and POCs network, it is recommended that, a national register of HCW treatment and disposal facilities be developed. Furthermore, it is recommended that a listing and mapping of existing waste management facilities, technologies, permit, and license holders be conducted, along with the collection of contact details and capacities. This register will facilitate the provision of a reliable contingent plan for the treatment of the laboratory waste as well as the identification of alternative solutions for recycling and recovery of controlled and valuable waste streams.

The development of an integrated and comprehensive network of treatment and disposal facilities will motivate the community to become self-sufficient in waste management. Besides providing opportunities for sustainable waste management, this network will also provide a valuable data related to waste management to the relevant authorities. Such data can be always used for the improvement of the waste management system, as well as for the planning of future activities and investments in human and environmental health.

The Register of Laboratory Waste Treatment Facilities/Operators can be included in the National Register of Licensed Waste Management Facilities or Operators.

9. Financing of Sustainable Healthcare Waste Management

The economic implications of developing and maintaining adequate waste treatment and disposal infrastructure present significant challenges, especially for LMICs. This section provides a comprehensive guide to the economic aspects of healthcare waste treatment and disposal. It addresses the financial implications of waste management, including the costs and investments required for the available funding mechanisms, and the long-term economic benefits and sustainability of robust waste management systems. The financing of healthcare waste management operations may vary depending on the country, region, and healthcare system in place. To establish a safe, effective, and sustainable healthcare waste management system, it is necessary to develop a sustainable plan for health care waste management. The plan can be developed at the national, regional, municipal, or institutional level, if it is consistent national legislation and/or international regulations and best practices. The healthcare waste management sustainability plan along with its level of implementation will further identify investments, operations, and cost implications to inform resource mobilization strategies.

9.1 - Investment Costs

The investment costs for healthcare waste management can vary significantly depending on numerous factors such as the size of the healthcare facility, the volume and type of waste generated, regulatory requirements, technological alternatives, and geographical location (Figure 48).

Initial Capital Investment

The establishment of healthcare waste management infrastructure requires a substantial initial capital investment. The construction of advanced incineration plants, autoclaves, engineered landfills, and waste-to-energy facilities requires a significant financial investment. For instance, the cost of constructing a modern incinerator that meets international standards[24] including pollution control technologies, can be expensive depending on capacity and technological specifications.

Technological Investments

Investing in state-of-the-art technology is crucial for ensuring the effectiveness and efficiency of waste treatment facilities. Technologies such as autoclaving, microwaving, and chemical disinfection systems, while less environmentally damaging, also require significant financial investment. The implementation of these technologies requires the acquisition of specialized equipment and infrastructure modifications to ensure the effective management of healthcare waste treatment.

Operational Costs

The financial burden of healthcare waste management is compounded by the costs associated with its operation. Such costs include those associated with fuel, maintenance, labour, and compliance with environmental and safety regulations. For example, autoclaves and other non-burn technologies, despite their environmental benefits, still require significant operational funding. Furthermore, regular monitoring, maintenance, and compliance with safety and environmental regulations contribute to the overall financial burden.

Training and Capacity Building

It is similarly imperative to direct investment towards the training and capacity building of personnel involved in waste management. This includes healthcare workers, waste management personnel, and regulatory bodies. The implementation of efficacious training programmes guarantees the appropriate segregation, management, and disposal of waste, thereby reducing the risk of contamination, and enhancing overall efficiency. The costs associated with these training programs, while substantial, are necessary for the sustainable operation of waste management systems.

Infrastructure Maintenance

It is of paramount importance to implement a long-term infrastructure maintenance programme to guarantee the durability and effectiveness of waste management facilities. This involves regular inspections, repairs, and upgrades to maintain compliance with international standards and to prevent environmental contamination. The financial implications of infrastructure maintenance must be incorporated into the comprehensive economic plan for healthcare waste management .

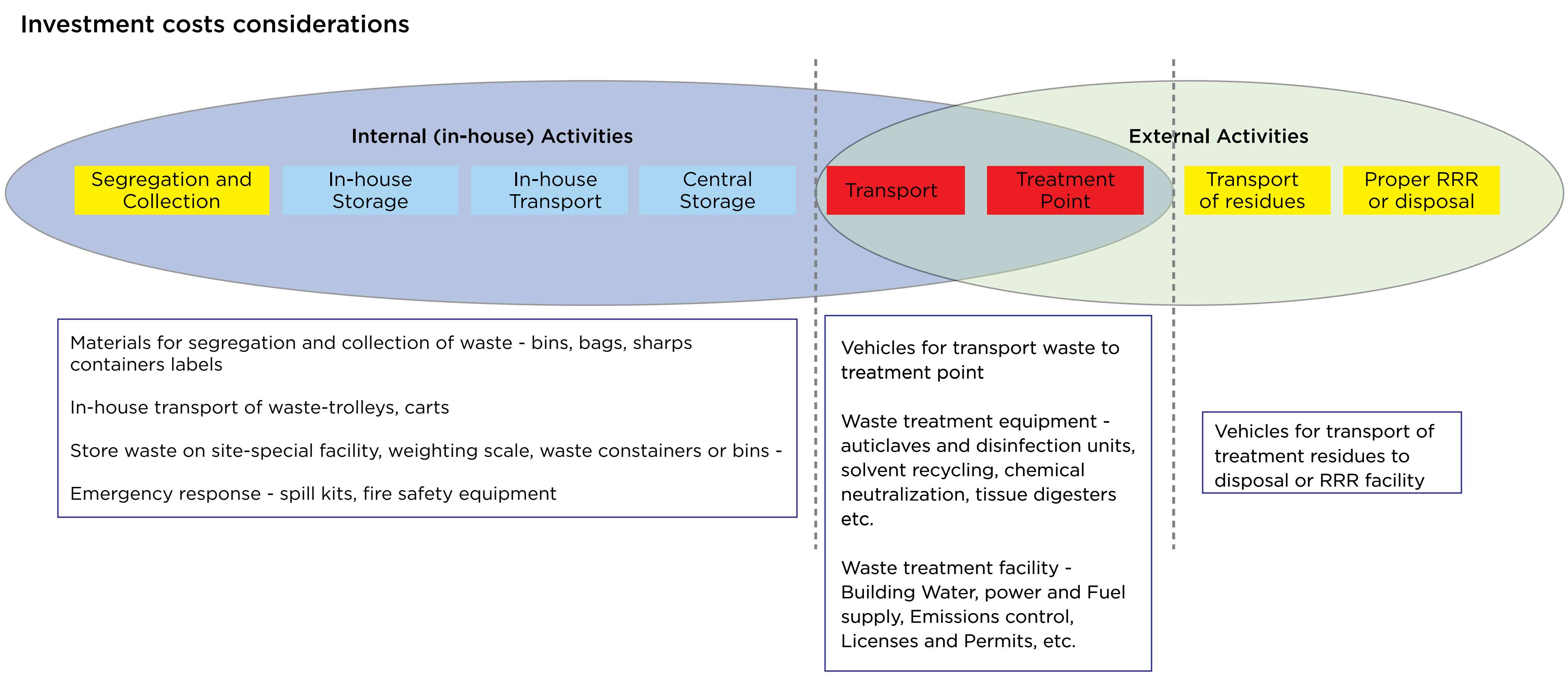


Figure 48 Investment cost considerations

Funding Mechanisms

International Aid, Grants Philanthropists

In regions with limited resources, international organizations and donor countries may offer financial assistance for the implementation of healthcare waste management projects. These funds could be in the form of grants or low-interest loans. Philanthropic organizations may also provide funding for waste management initiatives particularly those with a strong commitment to the cause and the necessary resources to invest.

Research Grants and Funding

Research institutions and universities may be awarded grants or funding to conduct research on innovative waste management techniques or technologies.

Corporate Social Responsibility (CSR) Initiatives

Pharmaceutical companies, medical equipment manufacturers, and other healthcare-related businesses may choose to invest in waste management initiatives as part of their CSR efforts.

Public-Private Partnerships (PPPs)

It can be argued that public-private partnerships (PPPs) represent a viable solution to the funding challenges faced by low- and middle-income countries (LMICs). By leveraging private sector investment, PPPs can facilitate the financing of the construction and operation of waste treatment facilities. Private entities contribute the requisite capital, expertise, and efficiency, while the public sector provides regulatory oversight and ensures that public health goals are met. The successful adaptation of PPP models from other sectors can be adapted to the healthcare waste management sector to optimize resources and achieve better outcomes.

CASE STUDY 2:

MEDICAL WASTE SERVICES LIMITED (GHANA) – PPP application

The Policy and Guidelines for Healthcare Waste Management for Ghana (2006) recommended the use of incinerators of which most healthcare facilities ultimately employed. However, the majority of these facilities utilized single-chambered incinerators, which have been identified as a significant environmental concern. The Government identified this issue and committed all relevant resources to the revision of the policy. The new version was launched in July 2020 promoting the use of more environmentally friendly treatment systems including microwave, and steam technologies etc.

The President, in his State of the Nation Address, in 2021 stated: “We shall establish 16 recycling plants and 14 medical waste treatment facilities across the country. This Centralized Medical Waste Treatment Facility will serve the purpose of collecting and treating hazardous components of healthcare waste which includes used syringes, blood-stained materials, pathological waste, Covid-19 waste and waste from vaccination exercises.”

It was agreed that the medical waste treatment facilities would be operated on a public-private partnership model. Moreover, they would assume responsibility for the management of waste generated by government-owned healthcare facilities. The private partner can sign individual contracts with privately owned healthcare providers.
Medical Waste Services Limited (MWSL), a subsidiary of the Jospong Group of Companies, which is a private entity in Ghana, was selected to provide comprehensive medical waste management services to healthcare facilities in Ghana. It was agreed that the following services should be included in the PPP model:

- The training of healthcare staff in the implementation of waste segregation and other protocol for the management of healthcare waste.
- The supply of color-coded bins and liners for the segregation and storage of waste.
- The collection and transportation of hazardous components of healthcare waste conducted in using specialized trucks.
- The treatment and disposal of hazardous healthcare waste conducted in environmentally friendly utilizing technologies that are environmentally responsible.

MWSL has established centralized medical waste treatment facilities in the various regions of the country. These facilities utilize non-incineration systems such as microwaves and autoclaves with integrated shredders. Periodic quality control and sterility tests are conducted using biological indicators to ensure safety and compliance. The safe disposal of treated waste received and treated waste is logged and reported to the relevant authorities and disposed of at dedicated engineered landfills. The facilities have received and treated 600 tons of infectious waste over the past twelve months.

MWSL ensures adequate training of all staff including engineers, janitors, marketers, quality control officers etc. The company is committed to innovation, research and development and has therefore established a dedicated team to oversee these activities.

International Grants and Loans

International grants and loans from development banks including the World Bank, the African Development Bank (AfDB), and the Global Environment Facility (GEF) are crucial sources of funding. These institutions provide financial assistance and technical support to help LMICs develop their healthcare waste management capacities. For example, the Global Environment Facility (GEF) and the Green Climate Fund (GCF) provide financial assistance for projects that offer significant environmental benefits, including waste management initiatives.

National Budget Allocations

National governments should prioritize healthcare waste management in their budgetary allocations. Allocating sufficient funds from national budgets for the construction and maintenance of waste management infrastructure is essential. This demonstrates the government's commitment to protecting public health and the environment. Additionally, governments can introduce waste management fees for healthcare facilities, thereby generating a steady stream of revenue to support waste management activities.

Carbon Financing

Carbon financing is an innovative funding mechanism for healthcare waste management projects. Projects that reduce greenhouse gas emissions, such as waste-to-energy initiatives, can generate carbon credits. These credits can be sold on international markets, generating revenue that can be reinvested in waste management infrastructure. Engaging with international carbon markets provides a viable source of funding to help offset the initial investment required for advanced waste management technologies.

9.2 Operating Costs

The operating costs for healthcare waste management include the ongoing costs of managing, handling, and disposing of healthcare waste. These costs can vary depending on factors such as the volume and type of waste generated, the efficiency of the waste management processes, regulatory requirements, and the chosen methods of waste treatment and disposal (Figure 49).

The following are some of the sources of funding for operational costs:

- **Government Budget Allocation:** Many governments allocate funds from their budget to the management of healthcare waste. This may form part of the overall healthcare budget or alternatively, it may be a separate allocation specifically for waste management.
- **Healthcare Facility Budgets:** Hospitals and other healthcare facilities often have their own line-budgets for waste management. They may allocate funds for purchasing waste disposal equipment and supplies, commodities, hiring personnel, and implementing waste segregation programs.
- **Cost recovery model:** In some cases, healthcare facilities may charge user fees to cover the cost of waste management services. A nominal fee may be charged to patients or healthcare service users as part of their treatment or service.
- **Public-Private Partnerships (PPPs):** In some cases, governments form partnerships with private companies or organizations to manage healthcare waste. These partnerships can involve private companies providing waste management services in exchange for payment from the government.

- **Insurance Schemes:** In countries with health insurance schemes, a portion of insurance premiums may be allocated towards covering healthcare waste management costs.
- **Environmental Taxes and Levies:** Some governments impose taxes or levies on activities that generate healthcare waste, such as the sale of medical products or the use of certain medical procedures. The revenue generated from these taxes can be used to fund waste management efforts.

Community Contributions - In some communities, residents may volunteer their time or resources to support waste management efforts, such as organizing clean-up campaigns, awareness- raising campaigns or providing educational outreach.

CASE STUDY 3:

COST RECOVERY MODEL FOR THE NATIONAL EQUIPMENT CALIBRATION CENTER (KENYA) – Business plan for NPHL – Model to consider for medical waste

The Kenya National Equipment Calibration Center (NECC) was established in June 2017, with funding from the Ministry of Health and CDC through PEPFAR funding as a Center of Excellence (COE) to enable the Ministry of Health have in-house capacity for equipment maintenance and calibration services. This program aims to ensure high-quality test services for patient diagnosis and monitoring.

The Program is focused on the calibration of auxiliary laboratory equipment. This is because auxiliary equipment is the primary diagnostic equipment used in most laboratories; its maintenance has a great impact on the overall performance of the laboratory. The calibration of this equipment is less complex and easier to scale up. The main gap that informed the establishment of the COE was the lack of equipment service contracts for the majority of facilities and where available these were very expensive and not sustainable.

The program enabled the MOH to enhance its capabilities in the following areas: 1). Working with the MOH on refresher training for public sector biomedical engineers and technicians on laboratory equipment management, a critical aspect of the HIV/TB clinical cascade. The trained MOH engineers are a readily accessible resource at the national and county levels. Counties are working with Clinical Implementing Partners (IPs) to provide support to biomedical engineers in carrying out facility level of equipment maintenance 2). The creation of equipment management systems (online remote log in system) enables the monitoring of equipment sent for calibration at the COE as well as the tracking of preventive maintenance service schedules and annual service schedules remotely.

The in-county capacity is currently comprised of the following: training of trainers (TOTs) for bio-meds on auxiliary equipment maintenance (12 trained), basic training on auxiliary equipment maintenance for MOH County biomedical engineers (72 trained), BSC certification training by Eagleson Institute for bio-meds (10 trained), in-depth refrigeration training for bio-meds (12 trained) and Gene Expert basic maintenance and troubleshooting training for bio-meds (24 trained).

The following auxiliary equipment being serviced, calibrated and certified at the NECC include microscopes, centrifuges, weighing scales and balances, refrigerators and freezers, shakers and vortexes, pipettes, incubators, autoclaves, timers, thermometers, and water baths. Additionally, the National based biomed (10) facilitate the t calibration of BSCs across the 47 counties in Kenya.

To address the issue of donor dependency in the running of the NECC, NPHL with the support of AMREF has sought the services of a consultant to develop a 5-year business plan with the aim of implementing a cost recovery model & sustainability trajectory for the program. The reasons for developing the business plan (cost recovery model) were to conceptualize integrated view of NECC operations, foster mutual understanding among stakeholders, determine financial requirements and the application of the funds, drive resource mobilization to support staff, equipment, physical facilities etc. provide guidance and direction for NECC employees of the and to engage with partners. This includes donors, suppliers, financiers etc.

The development of the business plan (cost recovery model) comprised the following steps:

1. Inception meetings with NPHL and key stakeholders to agree on project timelines and expectations
2. Review of relevant documentation within COE
3. Site visits to hospitals and laboratories that are currently using or have the potential to use NPHL's calibration services
4. Conduct a SWOT analysis for the COE
5. Business plan development and validation
6. Training of staff and stakeholders on the business plan.

The business plan included the following prospects: 1). 8,200 health facilities visited are under the National Health Insurance Fund (NHIF). 2). 150 facilities – mostly private - in 37 counties are already utilizing the NECC. 3). In the initial phase, all sampled facilities (Thika Level 5 Hospital, Kenyatta National Hospital, Coptic Hospital, and St. Francis Community Hospital, Kasarani) have expressed willingness to utilize COE services.

The status of implementing the business plan is as follows: 1). Currently seeking approval of the cost recovery model concept from the Permanent Secretary (PS), Ministry of Health. 2). Seeking approval of implementation seed budget from AMREF 2024/2025 budget 3). Seeking approval of NECC Bank Account opening by PS, Treasury 4). Mobilizing funds from donors 5). Recruiting Business Development Officer 6). Developing a sales pipeline.

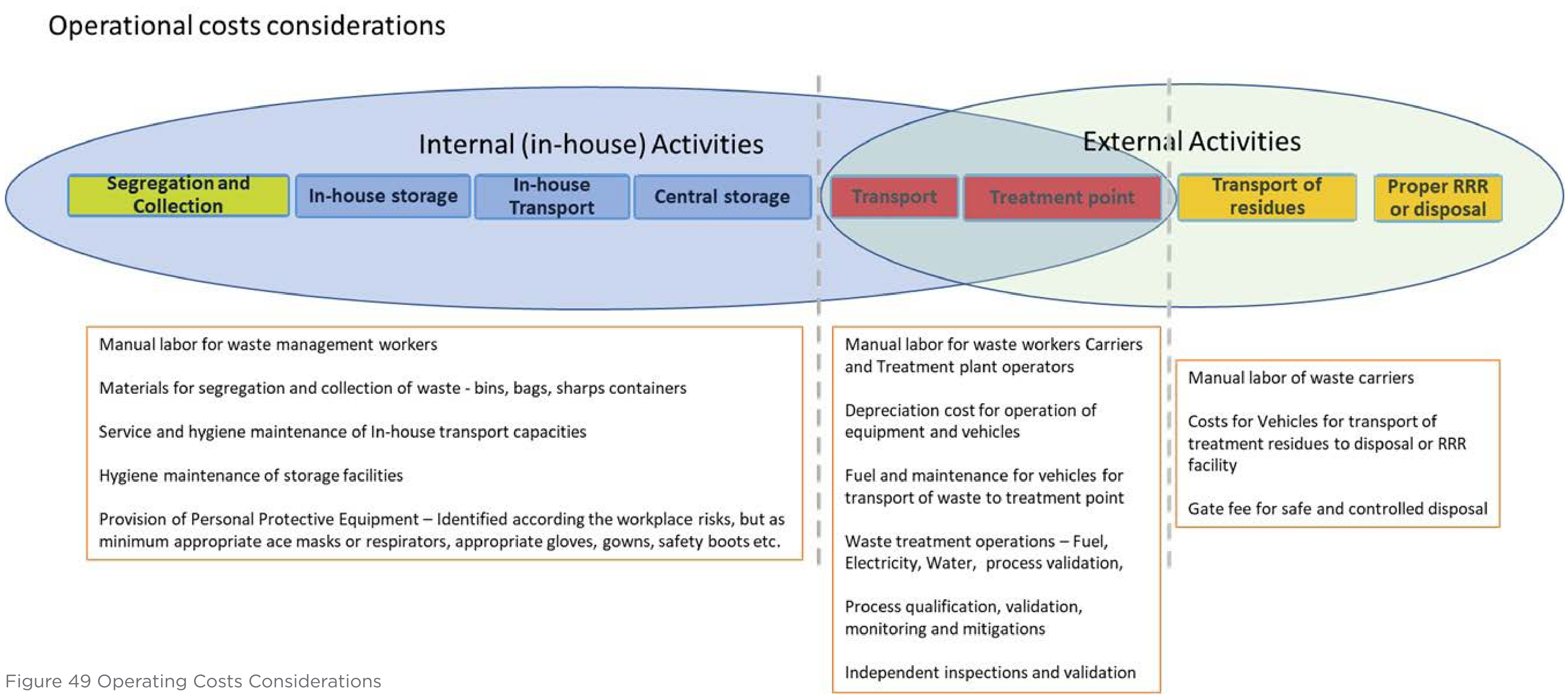


Figure 49 Operating Costs Considerations

Internal Activities

a) Training - staff handling waste at all levels (laboratory staff, riders, and incinerator operators)
b) Repairs, Servicing & Maintenance of equipment
c) Electricity cost
d) Equipment validation (e.g. Biological Indicators)
e) Regulatory requirements costs (license fee - Annual License Renewal & Environmental Assessments)

External Activities

a) Vehicles or riders for transport of waste to treatment point

9.3 Costing Tools

Costing tools play a crucial role in healthcare waste management by providing facilities with the necessary framework to assess, plan, quantify, and allocate resources effectively. The existence and importance of different costing tools, including but not limited to the Expanded Costing Analysis Tool (ECAT), Individualized Rapid Assessment (I-RAT), and the Waste Cost Assessment Framework (WCAF) serve as invaluable resources for acquiring the essential data pertaining to laboratory waste management. This data will be primarily useful in quantifying and costing the waste generated by healthcare facilities and informing planning and adequate resource allocation (budgeting) for proper waste management

The tools below provide assistance to healthcare facilities in the areas of budgeting, planning, and implementation of waste management strategies, with a particular focus on resource-constrained settings.

The ECAT - Expanded Costing Analysis Tool (https://www.washinhcf.org/resource/hcwm-expanded-costing-analysis-tools-ecat-high-income-countries-2/) developed by the WHO and WASH is a comprehensive costing tool tailored to analyze the costs and forecast a budget related with healthcare waste management in Low-Income Countries.

I-RAT - The Individualized Rapid Assessment Tool (IRAT) (https://www.technet-21.org/en/resources/ tool/individualized-rapid-assessment-tool-i-rat), was developed as part of the UNDP GEF Global Project on Healthcare Waste. The I-RAT is based on the WHO's Rapid Assessment Tool (RAT), which forms part of the WHO's overarching strategy to reduce the disease burden caused by poor healthcare waste management (HCWM) through the promotion of best practices and the development of safety standards. While the RAT evaluates the HCWM situation at national level, the IRAT of the UNDP GEF Project is intended to be used at the healthcare facility level.

WCAF – The Waste Cost Assessment Framework, (https://aslm.org/resource/waste-cost-assessment-framework-wcfa-v2-0-strategic-web-based-tool-for-laboratory-waste-management/), was created jointly by US CDC and Roche Diagnostics as part of a public-private partnership for the waste generated by the VL/EID testing platforms in PEPFAR-supported countries. It provides a structured approach to cost accounting and financial management related to healthcare waste. This tool enables healthcare facilities to quantify, track and analyze waste management costs, identify areas for improvement, and optimize resource allocation for sustainable waste management practices. https://aslm.org/resource-centre/?search=WCAF

The existence of these diverse costing tools highlights the importance of tailored approaches to healthcare waste management, considering factors such as resource availability, risk assessment, and financial sustainability. Furthermore, Key Performance Indicators (KPIs) for waste management are available.[26]

Economic Benefits

Investing in healthcare waste management infrastructure offers substantial economic benefits. Improved waste management reduces the incidence of disease transmission, which in turn lowers healthcare costs and improves public health outcomes. For example, effective management of medical waste prevents the spread of infections within healthcare facilities and the broader community, thereby reducing the economic burden of disease outbreaks.

Furthermore, waste-to-energy technologies offer an additional economic benefit by generating energy from waste materials. This not only helps to manage waste more effectively but also contributes to the energy needs of the country, reducing reliance on fossil fuels and enhancing energy security. The sale of energy produced from waste can provide a revenue stream to support the operation and maintenance of waste management facilities.

9.4 Long-Term Sustainability

Ensuring the long-term sustainability of healthcare waste management systems in LMICs requires ongoing investment and capacity building. Training healthcare workers and waste management professionals in best practices is essential to maintain high standards of waste segregation, handling, and disposal. Educational campaigns can raise awareness about the importance of proper waste management among the public, fostering a culture of compliance and environmental responsibility.

Regular monitoring and enforcement of regulations are crucial to maintaining the integrity of waste management systems. Governments must invest in regulatory bodies to ensure they have the resources and authority to conduct inspections and enforce compliance. Additionally, adopting innovative technologies that minimize environmental impact and enhance efficiency can bolster the sustainability of waste management systems.

The economics of healthcare waste treatment and disposal in LMICs requires significant initial investments, ongoing operational costs, and the need for sustainable funding mechanisms. By leveraging public-private partnerships, international funding, and innovative financing options like carbon credits, countries can develop and sustain effective waste management systems. The long-term economic benefits, including improved public health and energy production, make these investments a sound financial decision. To ensure the long-term sustainability of these systems, it is essential to maintain a continuous investment in infrastructure, training, and regulatory enforcement. By adopting a comprehensive and strategic approach, LMICs can enhance their national capacities for healthcare waste management, thereby protecting both public health and the environment.

10. Reporting and Monitoring

To establish control of the waste management system, it is necessary to implement specific monitoring, recordkeeping, and reporting measures. Monitoring and reporting are essential waste management activities for any establishment including healthcare facilities and laboratories. They ensure the safety of the public, facilitate effective waste reduction, and guarantee compliance with environmental regulations. Governments and environmental bodies have strict rules regarding waste disposal, and failure to comply can result in significant penalties Therefore, regular monitoring and reporting ensures that these rules are being implemented, thereby avoiding legal repercussions and potential harm to the environment.

Monitoring and reporting in waste management, provides a clear picture of the amount and types of waste being generated as well as how each waste category is finally treated and disposed of. This information is critical for planning and implementing any waste reduction strategies for the entity/facility.

Monitoring and reporting are essential waste management processes that facilitate the identification of trends and patterns in waste generation and over time. Monitoring reveals whether waste generation is increasing, decreasing, or remaining constant, allowing for the implementation of appropriate actions. By analysing the data collected through monitoring and reporting, it is then possible to forecast future waste generation and plan accordingly. Facilities should develop Key Performance Indicators (KPIs) for their HCWM programs to monitor the aforementioned items (weight of waste, cost to treat waste, including labour, and cost of disposal of waste).

In addition to providing control of the course, this monitoring and reporting will provide sufficient valuable information and data about system performance and potential improvements. The report also can be used as evidence of compliance with specific obligations, as a basis for individual cost justification, and to provide full traceability of all waste-related activities carried out by all parties involved in the waste management system.

In the absence of any regulatory requirements, the system for monitoring, record keeping, and reporting could be designed to suit the specific waste management operations. However, it should include at least the following elements:

- Waste streams, origin, and quantity (daily, monthly, annually).
- Waste Logs from consignment (date, amount, the destination of the waste).
- Accidents and incidents logbook.
- Evidence of waste consignment (consignment notes for transport, storage, treatment).
- Contracts with materials and service providers.
- Evidence of performed services (treatment process logs, signed consignment notes, transport documents, etc.).
- Financial review regarding waste-related issues (taxes, utilities (water, energy, etc.), materials, and services).
- Waste reporting evidence (legally required).

11. Health and Safety

Laboratories are generally considered a hazardous working environment. All laboratory workers are at risk of exposure to numerous potential hazards including chemical, biological, physical, mechanical, and radiological hazards. Therefore, they must be aware of the potential hazards in their work environment, as this makes them more vulnerable to occupational exposures, injuries, and accidents.

The materials (such as specimens, chemicals, reagents, biological material, consumables, etc.) that are used in the laboratories for diagnostics, to run assays, and for research generate wastes in large quantities which can be in the form of liquid, solid, or sharps. These wastes are presumed to be potentially contaminated. Therefore, it is evident that laboratory waste is considered as the most hazardous type of waste due to its complex composition. The potential risks associated with the different categories of waste should therefore be identified, evaluated, and mitigated through a risk assessment process.

A risk assessment is a systematic process (not limited to waste) (Figure 50) of gathering information and evaluating the likelihood and consequences of exposure to or release of workplace hazard(s) and determining the appropriate risk control measures to eliminate or reduce the risk to an acceptable level. Understanding how much exposure to a hazard poses health risks to workers is essential to eliminate appropriately, control, and reduce those risks.

A risk assessment aims to answer four basic questions:

- What can happen?
- How likely is it to happen?
- What are the consequences if it does happen?
- What remains after the process?

According to standard laboratory practices, it is necessary to conduct periodic risk assessments for work with chemical hazards, including carcinogens and non-carcinogens, biological hazards, and physical hazards such as noise, radiation, musculoskeletal injury, and needle stick injuries. These assessments provide the scientific basis for developing Standard Operating Procedures (SOPs) for the workplace.

The general four-step process for risk assessment is as follows:

1. Identify the hazards or risks.
2. Assess or evaluate the hazards.
3. Implement control or mitigation measures.
4. Check the performance of the control measures.

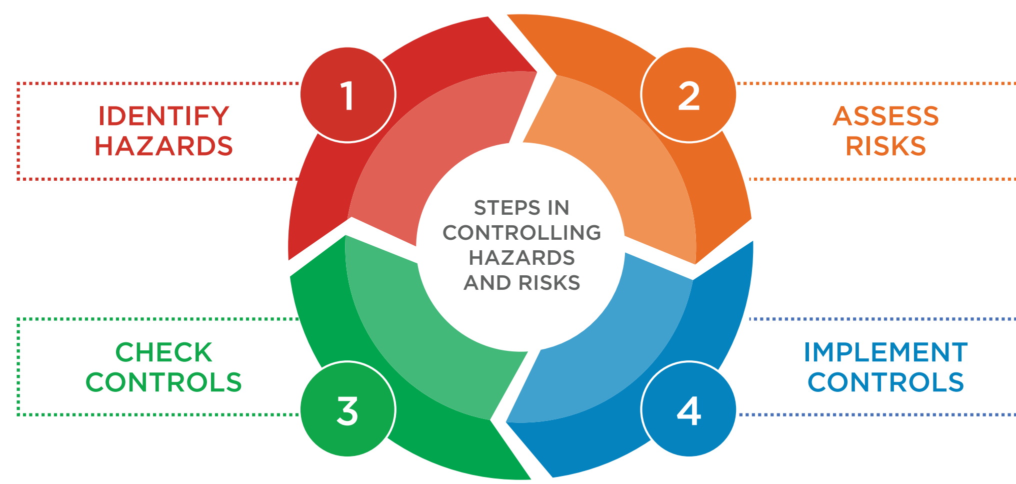


Figure 50 Risk Assessment Process Steps

References for assistance in the development of the risk assessment procedures can be found on:
https://www.cdc.gov/niosh/topics/riskassessment/default.html
https://www.osha.gov/shpguidelines/hazard-Identification.html
https://osha.europa.eu/en
https://osha.europa.eu/en/publications/risk-assessment-tool/view
https://www.who.int/publications/i/item/occupational-health---a-manual-for-primary-health-care-workers

11.2 Laboratory Biosafety and Biosecurity

Biosafety is the discipline addressing the safe handling and containment of infectious microorganisms and other hazardous biological materials and agents, as well as, the measures taken to prevent the unintentional release of the same. Biosafety measures are designed to protect healthcare workers and the public from accidental or unintentional exposure to biological agents. Biosafety measures include using personal protective equipment (PPE), such as gloves, goggles, and laboratory coats, as well as implementing standard operating procedures (SOPs) for handling, storing, and safely disposing of biological materials.

Biosecurity, on the other hand, refers to measures taken to prevent the intentional misuse of biological agents by individuals or groups with malicious intent. Biosecurity measures are designed to prevent unauthorized access to biological agents, theft, sabotage, or accidental release, thereby minimizing the risk of transmitting infectious agents or diseases, including pandemic diseases and bioterrorism. Biosecurity measures include access control, such as the implementation of security clearances and background checks, as well as physical security measures, such as surveillance cameras and alarms. Furthermore, laboratories and research institutions have established protocols for the secure storage, and transportation of biological agents, as well as special SOPs for addressing unexpected situations, incidents, and emergencies.

The facility's biosafety professionals and other health and safety personnel must perform and review the risks associated with healthcare waste using the appropriate risk assessment tools (checklists). Management and leadership are responsible for supporting and providing resources to implement risk mitigation measures. All healthcare workers in the institution are responsible for ensuring the successful implementation and compliance with the safety mitigation measures put in place following the risk assessment procedure. In addition, all healthcare workers should strive to develop a culture of safety and recognize that safety is everyone's responsibility (Figure 51).

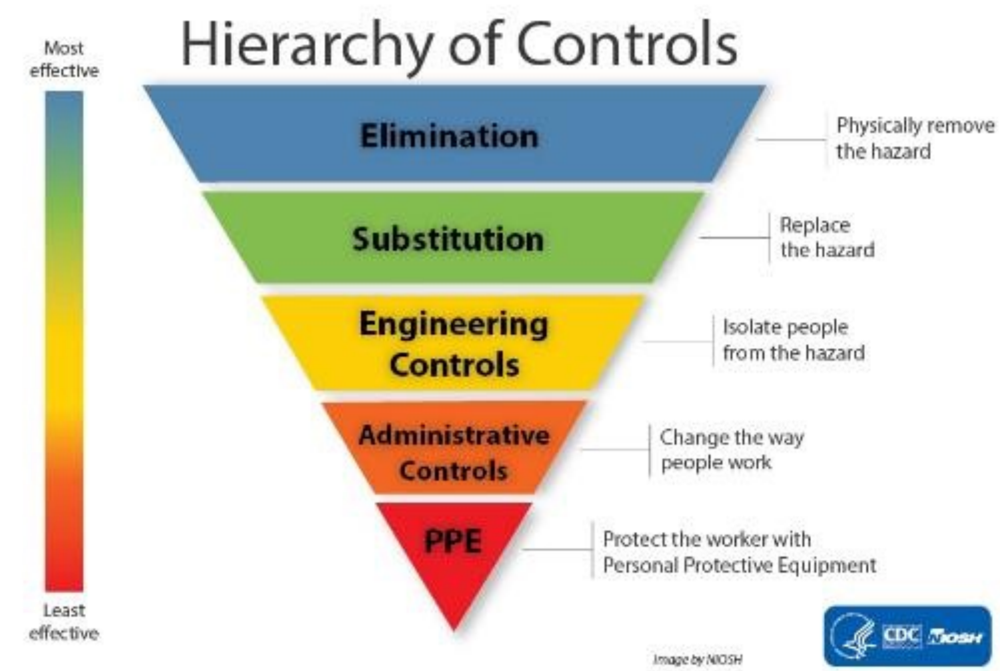


Figure 51 Biosafety Hierarchy of Controls

Image link: https://www.cdc.gov/niosh/hierarchy-of-controls/about/index.html

It is not possible to avoid the generation of waste in clinical laboratories, given the procedures and processes that are performed in the laboratories. The management of healthcare waste including chemical safety programs is considered part of laboratory biosafety and biosecurity. Please find enclosed links to specific biosafety and chemical safety guidelines (Figure 51).

https://bio.libretexts.org/Bookshelves/Microbiology/Microbiology_%28OpenStax%29/13%3A_Control_of_Microbial_Growth/13.01%3A_Controlling_Microbial_Growth

https://www.cdc.gov/labs/bmbl/?CDC_AAref_Val=https://www.cdc.gov/labs/BMBL.html

https://www.who.int/publications/i/item/9241546506

https://www.who.int/publications/i/item/9789240011311 https://africacdc.org/download/biosafety-and-biosecurity-initiative-2021-2025-strategic-plan/

https://web-archive.oecd.org/2023-09-20/516994-work-on-chemical-safety-and-biosafety.pdf

https://www.osha.gov/publications/bytopic/laboratory-safety

https://echa.europa.eu/

Figure 52 Cover pages of the current relevant documents

11.3 Occupational Health and Safety related to laboratory waste management

The occupational safety of personnel and workers handling waste is often not given sufficient attention. Healthcare waste-management policies or plans should include a continuous monitoring arrangement for workers' welfare, health, and safety. This is to ensure that the correct handling of wastes is followed during segregation, storage, collection, transportation, treatment, and disposal procedures.
The following are standard occupational health and safety measures:

- Develop a standardized set of policies, guidelines, and operating procedures for the management of healthcare waste including sharps, biohazardous and non-biohazardous wastes and chemicals. Training all personnel involved in waste management.
- Provision of adequate Personal Protective Equipment (PPE) to the personnel. Establish an occupational health program that includes personnel welfare, training, and medical countermeasures when necessary. These may include, for example, immunization, post-exposure prophylactic treatment, regular medical assessments, and surveillance. According to the WHO, all healthcare workers should receive the Hepatitis B vaccine to address the risk of Hepatitis B in healthcare settings.[27]

11.4 Safety in handling chemical wastes

Chemical waste consists of discarded solid, liquid, and gaseous chemicals, for example, those resulting from diagnostic and experimental work as well as from cleaning, housekeeping, and disinfecting procedures. Chemical waste from healthcare may be hazardous or non-hazardous. In the context of protecting health, chemicals are hazardous if they are toxic, corrosive, flammable, reactive, and or genotoxic.

Safety Data Sheets (SDS) provide employers, employees, emergency responders, and the public with basic information about the potential hazards associated with chemicals used in the workplace. They serve as a primary information resource for health, safety, and environmental professionals, facilitating quick reference and communication of chemical hazards and risk control mitigation measures.

The purpose of the SDS is to ensure that all workers who handle chemicals are provided with the requisite hazard information for their intended use. Furthermore, the SDS contains information regarding storage, transportation, and environmental impact. The SDS contains general information on each chemical, such as its properties (physical or chemical), health, and environmental health hazards; protective measures; and safety precautions for handling, storing, and transporting the chemical.

11.5 Safety in handling sharps

Appropriate precautions must be put in place to safeguard against exposure to sharps, blood, and body fluids. These precautions include:

i. Providing a purposely designed sharps container as close as practicable to the point of generation of the sharps;
ii. Providing appropriate PPE for potential blood and body substance exposures;
iii. Conducting compliance checks to confirm that all personnel are wearing the appropriate protective clothing;
iv. Investigating all incidents to identify causes of exposure
v. Take remedial action to eliminate risks;
vi. Occupational Safety & Health Committees or an appropriate forum must review incident reports and confirm appropriate action has been taken;
vii. Train staff in first aid and injury management procedures for sharps injury and body substance exposure;
viii. Reinforce the need for staff to report all incidents and injuries;
ix. Analyze statistics to identify any risk exposure trends for necessary interventions.

11.6 Standard Operating Procedures (SOPs) for Laboratory Waste Management

Standard Operating Procedures (SOPs) for laboratory waste management are essential for providing technical guidance to all personnel in laboratories that actively handle or manage biological agents and toxins that generate various streams or categories of biohazardous waste. In addition, waste management SOPs provide clear instructions on how to treat and dispose of these wastes safely and responsibly, in line with local regulations and best practices to minimize any associated health risks. [28]

11.7 Personal Protective Equipment (PPE) and proper use

Personal protective equipment, commonly referred to as "PPE," is equipment worn to minimize exposure to various hazards. PPE should be used in conjunction with other risk mitigation measures to provide sufficient protection. The selection of PPE should be based on risk assessment.

The most common PPE that is used in the clinical laboratories are:

- Respirators (different types)
- Safety goggles or face shields
- Protective gloves (different types)
- Protective clothes
- Protective overalls
- Protective footwear
- Full bodysuits

PPE is used across healthcare waste management as a "control measure" to mitigate the risks associated with waste. The correct and appropriate use of PPE must be exercised at all times based on a thorough risk assessment of the different waste handling procedures. It is the responsibility of the employer or management to ensure that adequate PPE is provided.

For the standard donning and doffing procedures for PPE as well as hand hygiene, refer to the following WHO links:

https://www.who.int/publications/i/item/WHO-HIS-SDS-2015.1

https://www.who.int/docs/default-source/patient-safety/how-to-handwash-poster.pdf?sfvrsn=7004a09d_

11.8 Safety in Spill Management

In the event of significant spillage, the primary objective is to contain the situation. It is essential that procedures clearly define the steps to be taken in the event of a spill, including the conditions under which emergency services such as the Local Municipal Council Fire Brigade section should be contacted. All personnel involved in spill management must receive comprehensive education and training in emergency procedures and handling requirements. Spill kits should be readily available throughout the hospital with their location known by all staff. Any spill kits that have been used should be disposed of with the corresponding type of waste that has been cleaned up. For example, used cytotoxic spill kits should be disposed of with cytotoxic waste. All spillages should be documented per department and facility. This will facilitate the development of effective training protocols designing training protocols.

Please find below a general spill management guide:

i. Identify the substance and evaluate the risk
ii. Protect the personnel
iii. Stop & contain the spill
iv. Label the area as contaminated
v. Decontaminate and clean the spill
vi. Dispose of waste appropriately
vii. Document the incident

12. Achieving Laboratory Sustainability

Healthcare laboratories are established to provide reliable diagnostic services to the communities they serve and influence the quality of public health. For laboratories to maintain this level of quality, they must embrace current trends in sustainability. Achieving laboratory sustainability is a multifaceted task that requires a comprehensive, holistic approach, focusing on establishing fundamental standards (Figure 52).

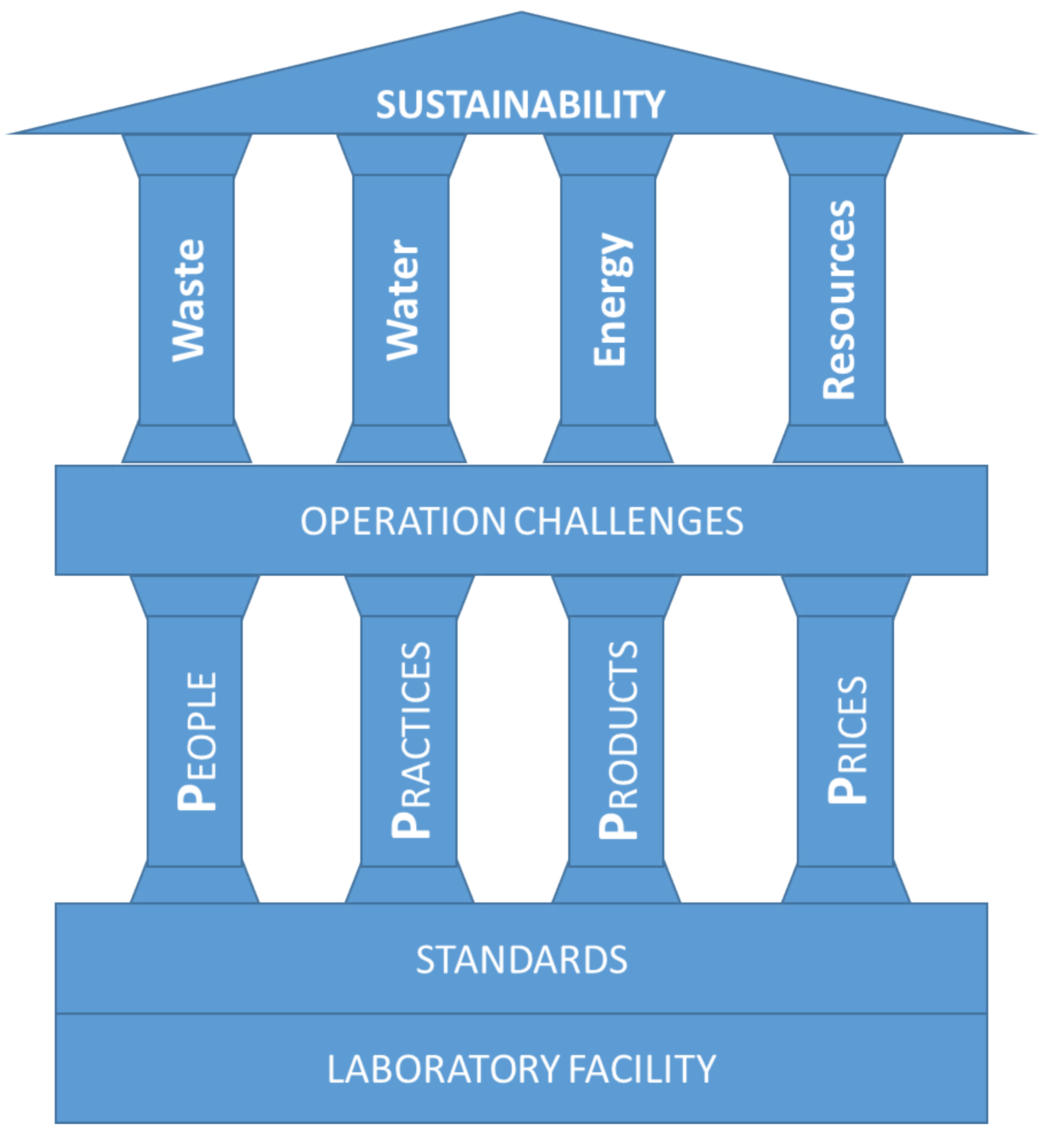


Figure 53 Schematic example of the essentials for sustainability

Fundamental standards are necessary to ensure quality. They are essential in establishing laboratories for numerous reasons, primarily related to safety, compliance, operational efficiency, and sustainability.

Laboratories often manage hazardous materials and complex processes. Fundamental standards ensure that safety protocols are in place to protect laboratory personnel from chemical, biological, and physical hazards. Laboratories must adhere to various local, national, and international environmental protection, occupational safety, and product quality regulations.

Establishing fundamental standards helps laboratories maintain compliance with these regulations, reducing the risk of legal penalties and enhancing their credibility in the marketplace. The most essential elements for implementation of any quality assurance standards are people, practices, products, and price.

People

- **Training and Awareness:** Train all laboratory personnel on sustainability practices, including waste management, energy conservation, and environmentally friendly materials. Sensitize staff on how their daily activities impact sustainability.
- **Inclusion:** Promote a diverse and inclusive culture that fosters innovation and holistic problem-solving in sustainability initiatives.
- **Sustainability Champions:** Designate team sustainability champions to encourage peer engagement and ensure adherence to sustainable practices.
- **Continuous Professional Development:** All laboratories must intentionally maintain, expand, and improve the knowledge and skills needed for the employees to perform in a professional context.

Practices

- **SOP Development:** Develop Standard Operating Procedures (SOPs) that incorporate sustainability throughout lab processes, including material use, disposal methods, and equipment usage.
- **Green Chemistry Principles:** In all research and development activities, implement green chemistry principles to minimize hazardous substances and improve material efficiency.
- **Continuous Improvement program:** Foster a continuous improvement and innovation culture, regularly reviewing practices to identify areas for greater efficiency and sustainability.

Products

- **Sustainable Procurement:** Establish a procurement policy favouring eco-friendly, biodegradable, and recyclable materials. Source products that are certified by recognized sustainability standards. Evaluate suppliers based on their commitment to sustainability and ethical sourcing practices.
- **Equipment Efficiency:** Invest in energy-efficient laboratory equipment and tools that reduce energy consumption and waste and ensure they are properly maintained to operate at peak efficiency.
- **Inventory Management:** Implement inventory management systems to minimize over-purchasing and waste of chemicals and consumables.

Price

- **Cost-Benefit Analysis:** Assess the financial implications of sustainable practices—initial investments may be higher, but the long-term savings from reduced water, energy consumption and waste disposal can be substantial.
- **Funding:** Explore funding opportunities and grants for sustainability initiatives and consider providing incentives for departments who actively participate in sustainability efforts.
- **Value Assessment:** Recognize the non-financial benefits of sustainability, including improved lab reputation, increased funding opportunities, and enhanced morale among staff. Consider investing in renewable energy sources or energy-saving measures to reduce operational costs over time.

Addressing Operational Challenges

Once these fundamental standards are in place, laboratories may face operational challenges related to waste management, water management, energy consumption and resources management. To address these challenges and receive the benefits of sustainability, the following steps can be taken:

Waste management: Implement a recycling program tailored to laboratory-specific waste types, including chemical waste, plastics, and electronic waste. Engage staff in regular training sessions about proper waste disposal methods to minimize contamination and maximize recycling efforts.

Water management: Monitor water usage closely and implement measures such as rainwater harvesting or greywater recycling where feasible. Regular maintenance checks on plumbing systems can prevent leaks and unnecessary water wastage.

Energy consumption: Conduct energy audits to identify energy-saving opportunities and implement recommendations. Upgrade energy-efficient equipment and lighting systems. Promote energy conservation practices among staff through training and awareness campaigns.

Resources management: Monitor and track resource consumption to identify areas for improvement. This is especially important for facilities that has certain challenges with access, availability and affordability of clean water and stabile and uninterrupted power supply, as well as provision of working materials, consumables, products, and equipment.

By addressing these operational challenges and embracing sustainable practices, laboratories can benefit from reduced environmental impact, cost savings, improved efficiency, and a positive reputation for responsible stewardship in the laboratory community and the public as well.

Implementing sustainable laboratory waste management practices offers several key benefits:

Environmental Benefits

- **Reduced Landfill Waste:** Sustainable practices minimize the volume of waste sent to landfills, conserving natural resources, and mitigating environmental impacts.
- **Lower Carbon Footprint:** Laboratories can significantly decrease their carbon emissions by adopting energy-efficient technologies and reducing hazardous waste.
- **Resource Conservation:** Sustainable methods promote the efficient use of water and energy, which are often consumed at much higher rates in laboratories compared to standard office settings.

Economic Benefits

- **Cost Savings:** Implementing sustainability programs can reduce operational costs through lower energy consumption and waste disposal fees. For example, labs that optimize procurement and waste strategies often see significant financial savings.
- **Incentives and Grants:** Many funding agencies favour laboratories with vital sustainability records, potentially increasing access to financial support for research initiatives.

Social Responsibility

- Improvement of the environmental infection control of diseases caused by agents found in traditional ecological environments, such as air, soil, and water, in addition to vector-borne or zoonotic diseases.
- **Enhanced Reputation:** Laboratories prioritizing sustainability can improve their brand image and foster stronger community relations by demonstrating a commitment to environmental stewardship.
- **Employee Engagement:** Sustainable practices can enhance workplace culture, attract talent who value environmental responsibility, and contribute to higher job satisfaction among staff.

Ultimately, laboratory sustainability is an ongoing process that requires commitment, flexibility, and innovation. By fostering a culture of sustainability, laboratories can not only contribute to environmental preservation but also realize substantial operational and financial advantages. We hope that this Guidance Document for improvement of laboratory waste management will contribute toward achieving laboratory sustainability.

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Note:

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Annex I – Basel Codes - List of Hazardous Characteristics

UN Class[5]	Code	Characteristics
1	H1	**Explosive**
		An explosive substance or waste is a solid or liquid substance or waste (or mixture of substances or wastes) which is in itself capable by chemical reaction of producing gas at such a temperature and pressure and at such a speed as to cause damage to the surroundings.
3	H3	**Flammable liquids**
		The word "flammable" has the same meaning as "inflammable". Flammable liquids are liquids, or mixtures of liquids, or liquids containing solids in solution or suspension (for example, paints, varnishes, lacquers, etc., but not including substances or wastes otherwise classified on account of their dangerous characteristics) which give off a flammable vapour at temperatures of not more than 60.5°C, closed-cup test, or not more than 65.6°C, open-cup test. (Since the results of open-cup tests and of closed-cup tests are not strictly comparable and even individual results by the same test are often variable, regulations varying from the above figures to make allowance for such differences would be within the spirit of this definition.)
4.1	H4.1	**Flammable solids**
		Solids, or waste solids, other than those classed as explosives, which under conditions encountered in transport are readily combustible, or may cause or contribute to fire through friction.
4.2	H4.2	**Substances or wastes liable to spontaneous combustion**
		Substances or wastes which are liable to spontaneous heating under normal conditions encountered in transport, or to heating up on contact with air, and being then liable to catch fire.
4.3	H4.3	**Substances or wastes which, in contact with water emit flammable gases**
		Substances or wastes which, by interaction with water, are liable to become spontaneously flammable or to give off flammable gases in dangerous quantities.
5.1	H5.1	**Oxidizing**
		Substances or wastes which, while in themselves not necessarily combustible, may, generally by yielding oxygen cause, or contribute to, the combustion of other materials.
5.2	H5.2	**Organic Peroxides**
		Organic substances or wastes which contain the bivalent-o-o-structure are thermally unstable substances which may undergo exothermic self-accelerating decomposition.
6.1	H6.1	**Poisonous (Acute)**
		Substances or wastes liable either to cause death or serious injury or to harm human health if swallowed or inhaled or by skin contact.

5 Corresponds to the hazard classification system included in the United Nations Recommendations on the Transport of Dangerous Goods (ST/SG/AC.10/1Rev.5, United Nations, New York, 1988).

UN Class[5]	Code	Characteristics
6.1	H6.1	**Poisonous (Acute)**
		Substances or wastes liable either to cause death or serious injury or to harm human health if swallowed or inhaled or by skin contact.
6.2	H.2	**Infectious substances**
		Substances or wastes containing viable micro organisms or their toxins which are known or suspected to cause disease in animals or humans.
8	H8	**Corrosives**
		Substances or wastes which, by chemical action, will cause severe damage when in contact with living tissue, or, in the case of leakage, will materially damage, or even destroy, other goods or the means of transport; they may also cause other hazards.
9	H10	**Liberation of toxic gases in contact with air or water**
		Substances or wastes which, by interaction with air or water, are liable to give off toxic gases in dangerous quantities.
9	H11	**Toxic (Delayed or chronic)**
		Substances or wastes which, if they are inhaled or ingested or if they penetrate the skin, may involve delayed or chronic effects, including carcinogenicity.
9	H12	**Ecotoxic**
		Substances or wastes which if released present or may present immediate or delayed adverse impacts to the environment by means of bioaccumulation and/or toxic effects upon biotic systems.
9	H13	Capable, by any means, after disposal, of yielding another material, e.g., leachate, which possesses any of the characteristics listed above.

Tests

The potential hazards posed by certain types of wastes are not yet fully documented; tests to define quantitatively these hazards do not exist. Further research is necessary in order to develop means to characterise potential hazards posed to man and/or the environment by these wastes. Standardized tests have been derived with respect to pure substances and materials. Many countries have developed national tests which can be applied to materials listed in Annex I, in order to decide if these materials exhibit any of the characteristics listed in this Annex.

Annex II – Additional waste streams – E-Waste

In addition to the aforementioned waste streams, the laboratories often use various electronic devices and equipment for experiments, testing, analysis, and data collection. In line with the ongoing progress in digitalization, automation, and modernization of laboratories, it is to be expected that some laboratory equipment will become outdated, redundant, and discarded. When these devices reach the end of their useful life or need to be replaced, they become electronic waste (e-waste).

It is important to note that laboratory e-waste can be contaminated with biological or chemical agents. It can also contain hazardous materials such as PCBs, refrigerants, hazardous liquids or gases, or heavy metals. Therefore, these wastes must be accurately assessed, decontaminated, and handled with care to reduce the potential for cross-contamination or damage to human and environmental health. Proper disposal and recycling of this e-waste is essential to minimize environmental impact and ensure compliance with international conventions.

Medical diagnostics equipment is frequently contaminated with specific biological materials, which is not found in other types of electronic devices.

Many laboratories have protocols or standard operating procedures in place for the responsible disposal of electronic equipment. These may involve recycling programs, donations to organizations in need, or certified e-waste disposal services. Furthermore, some laboratories may implement measures to extend the lifespan of electronic equipment through maintenance and upgrades, thereby reducing the amount of e-waste generated.

Unlike other businesses, medical facilities must ensure the confidentiality of information about doctors, dentists, patients, employers, and employees, both in digital and paper form. This is in addition to the need to dispose of their electronic waste or patients' records without any worry about confidential information.

The management of e-waste at the point of production enables the repair and maintenance of discarded electronics to be reused through laboratory learning activities (i.e., demonstration/training, etc.) which can lead to a reduction in e-waste and facilitate sustainable education and a global transition towards a circular educational economy. However, the disposal of medical equipment presents a unique challenge, directly depending on the capacities for e-waste management.

Effective waste management is not limited to the management of hazardous waste streams. Laboratory waste management plans must include non-hazardous waste streams, such as packaging materials, paper, cardboard, glassware, plastics, etc. The management of these waste streams could generate a certain income for the laboratories, which can be used for reimbursement of certain costs, or purchase of consumables for waste management. Laboratories must implement effective waste management practices to minimize environmental impact, protect human health, and comply with regulations. This includes implementing waste reduction strategies, segregating waste streams, labeling containers, providing training to laboratory personnel, and following appropriate disposal procedures in accordance with local, national, and international regulations and guidelines.

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