European Biosafety Network

WHITE PAPER

Closed-System Disposal Devices (CSDDs) and Airtight Sealing:

Preventing Worker Exposure to Hazardous Medicinal Products (HMPs) in Healthcare Waste Management

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1. Executive Summary

Europe's healthcare systems generate several million tonnes of waste each year. The WHO estimates that of the total amount of waste generated by health-care activities, approximately 85% is general, non-hazardous waste. The remaining 15% is considered hazardous material that may be infectious, toxic, carcinogenic, flammable, corrosive, reactive, explosive or radioactive. While hazardous waste makes up a small fraction of total healthcare waste, its properties mean that its management, handling and disposal is a priority for health and safety.

Hazardous Medicinal Product waste falls into this latter category and exemplifies the importance of proper waste management and disposal. A significant share of oncology-related waste contains hazardous medicinal products (HMPs) or residues from their use, including cytotoxic drugs, contaminated PPE, IV lines, infusion bags, wipes, surfaces and patient excreta. These substances are classified as carcinogenic, mutagenic or reprotoxic and can remain biologically active long after treatment. Despite growing awareness of HMP risks, the specific dangers created by inadequate waste handling and disposal remain under-recognised.

Only closed-system disposal devices (CSDDs) can prevent dangerous medicinal residues from escaping at the waste stage. CSDDs include airtight, mechanically heat-sealing continuous liner units, closed-fluid systems, and airtight rigid containers (only when they remain closed). Other containers such as open bins, reusable washout bins, and standard sharps containers, may be able to carry waste from hazardous medicinal products, but they do not adequately prevent exposure in clinical use.

Inadequate handling of this waste creates occupational hazards not just for frontline medical personnel such as doctors and nurses, but also for other hospital staff including porters, cleaners and waste handlers. Additionally, waste units which do not seal waste at the source have significant limitations in preventing the spread of contamination.

Healthcare waste is well documented to carry complex toxicological and environmental risks. Exposure to hazardous waste streams has been associated with infectious outcomes and with systemic effects such as endocrine disruption, metabolic disturbances and mutagenic or carcinogenic harm, particularly among healthcare workers and waste-handling personnel who face routine contact with contaminated materials (Cîrstea et al., 2025).

Surface contamination and dermal exposure persist as the dominant pathways through which HMPs reach workers, even when airborne levels are low or undetectable (Beigzadeh et al., 2025). These risks extend far beyond nurses to pharmacists, veterinary oncology staff, porters, cleaners and domestic workers, many of whom have limited access to specialist training despite high contact with hazardous waste streams.

At the same time, Europe continues to face large variations in how HMP waste is classified, managed and contained. Compliance with the Carcinogens, Mutagens and Reprotoxic Substances Directive requires engineered controls at every stage of handling, including disposal, yet practice often falls short of these legal obligations. Many facilities still rely on open or semi-open waste containers that allow leakage, vapour release or surface contamination - conditions that have been repeatedly linked to occupational exposure events. Strengthening waste management is therefore essential for meeting regulatory standards, reducing preventable illness and improving working conditions across oncology and related settings.

Closed-system disposal devices (CSDDs) offer a practical, evidence-based solution. Across multiple European and international evaluations, these systems consistently reduce contamination, lower exposure risk and improve workflow safety.

Lifecycle assessments show that both reusable sharps containers and heat-sealing continuous liner sealed systems deliver significant environmental benefits, including reductions in greenhouse gas emissions and large reductions in plastic and cardboard consumption when compared with traditional single-use or open systems. Although reusable sharps containers are not closed systems, their environmental performance is noteworthy. These environmental gains align with broader health-system commitments to sustainability and circular-economy principles.

This white paper brings together the scientific, regulatory, occupational-health and environmental evidence into a single, structured review.

This white paper examines:

- The toxicity profile and occupational risks associated with HMP waste
- The gaps and inconsistencies in current waste-handling practices across Europe
- The health and safety benefits of closed-system technologies
- The environmental advantages demonstrated through lifecycle analysis
- Practical and regulatory pathways to safer, compliant and sustainable waste management through the use of airtight sealing as the safest solution

The goal is to provide a clear, evidence-based foundation for improving safety and environmental performance, particularly where current open or semi-open waste systems leave workers exposed to unnecessary contamination, leaks and vapour release. The findings and recommendations address these gaps by setting out what is required to move beyond outdated containers that fail to protect staff or the environment.

This guidance is relevant not only for nurses and pharmacists who work with or around HMPs, but for every worker who may come into contact with cytotoxic waste. Porters, waste handlers, cleaners, veterinary oncology staff and other frontline personnel remain disproportionately affected when inadequate bins and poorly sealed liners allow hazardous residues to spread. Strengthening waste management therefore protects the full workforce whose roles are essential to health system safety.

2. Occupational Risk and the Waste Disposal Gap

2a. Occupational Exposure to Hazardous Medicinal Products

Hazardous medicinal products (HMPs) include antineoplastic, immunosuppressive, antiviral and hormonal agents whose active substances are classified, or may be classified, as carcinogenic, mutagenic or reprotoxic substances (European Commission, 2022, 2023, 2025; ETUI, 2022).

These medicines generate a distinct waste stream of contaminated infusion bags, syringes, personal protective equipment (PPE) and patient excreta that can retain measurable concentrations of active agents after administration.

While awareness of HMPs has grown, recognition of the specific risks posed by inadequate waste disposal remains insufficient. Failures in waste management can expose nurses, pharmacists, veterinary oncology staff, porters, cleaners and other ancillary personnel to hazardous residues (Capoor & Bhowmik, 2017; Musu & Vogel, 2018; Labrèche et al., 2021; HSE, 2023).

Healthcare workers may experience chronic, low-level exposure to multiple HMPs over many years (Leso et al., 2022; Musu & Vogel, 2018). Early environmental and biological monitoring demonstrated significant surface contamination and urinary excretion of cyclophosphamide and other cytotoxic drugs among pharmacy technicians and nurses in multiple hospital departments (Sessink et al., 1992). More recent systematic reviews of biological monitoring continue to find persistent low-level contamination in nurses and pharmacy staff despite improvements in safety protocols (Leso et al., 2022).

Chronic exposure has been associated with reproductive disorders, genotoxic effects and, in some studies, increased cancer risk (Connor et al., 2014; Ladeira et al., 2014; Ratner et al., 2010; Musu & Vogel, 2018).

A structured literature review concluded that occupational exposure to antineoplastic drugs increases the risk of miscarriage, congenital malformations and subfertility (Connor et al., 2014). An observational study of nurses handling cytostatic drugs found increased chromosomal aberrations and DNA damage despite the absence of clinical symptoms (Ladeira et al., 2014).

Population-based research links occupational exposure to antineoplastic drugs with increased cancer incidence among nurses (Ratner et al., 2010). Because cancers and reproductive disorders have long latency periods, the cumulative effects of inadequate containment may not become apparent for decades (Musu & Vogel, 2018). The broader public health burden extends beyond patients to families, communities and economies.

A review of the “forgotten” impacts of cancer highlights how poor handling of cytotoxic waste contributes to hidden occupational health risks (Viegas et al., 2017), while an ETUI report quantifies the substantial human and financial cost of occupational cancer across the EU (Vencovsky et al., 2020).

These risks extend beyond pharmacists and nurses. A study of hospital sanitation workers detected surface contamination and biological uptake of hazardous drugs in staff who did not prepare or administer medications, highlighting systemic gaps in training and containment practices (Labrèche et al., 2021). Guidance from the UK Health and Safety Executive stresses that training, risk assessments and exposure controls must cover all employees who may contact contaminated waste, including porters and housekeeping staff (HSE, 2023).

A recent systematic review comparing dermal and inhalation exposure to antineoplastic drugs across multiple workplace settings found that surface contamination is the dominant and most consistent exposure pathway, while airborne concentrations were typically undetectable or very low in healthcare environments, except in rare high-risk industrial settings. Across ten studies, dermal contamination levels varied widely depending on drug type, work practices and cleaning quality, underscoring that even low-level residues on gloves, equipment and work surfaces can present meaningful exposure risks. Inhalation risks were generally minimal during clinical handling but can become significant in manufacturing environments, highlighting the importance of tailored controls by setting. Overall, skin contact is the primary occupational exposure route for antineoplastic drugs, and effective risk reduction depends on strict handling protocols, regular decontamination, appropriate PPE and biological monitoring to identify low-level or cumulative exposures (Beigzadeh et al., 2025).

To minimise dermal and inhalation exposures, appropriate PPE such as chemotherapy-tested gloves, impermeable gowns and respiratory protection must accompany engineering controls such as closed system transfer devices and hermetically sealed waste management systems.

Evidence-based guidance emphasises that PPE is not a stand-alone solution; it should be integrated with closed systems, staff training and regular environmental monitoring (Dillon, 2020; HSE, 2023). Reproductive-age workers should receive additional medical surveillance given the potential for foetal harm (Connor et al., 2014).

By recognising HMP waste as a significant occupational hazard and implementing comprehensive containment and disposal strategies, healthcare organisations can protect workers from preventable illness and align with evolving EU occupational safety legislation (European Commission, 2022, 2023, 2025; ETUI, 2022).

Healthcare workers wearing PPE

2b. HMP Waste: The Disposal Gap

Despite improvements in compounding and administration safety, waste disposal remains the least standardised and least protected stage of the HMP life cycle. HMP waste includes any material that comes into contact with HMPs during storage, preparation, administration or disposal, such as infusion bags, syringes, IV tubing, vials, gloves, gowns, masks, wipes, sharps, contaminated PPE and patient excreta. Each of these waste streams can retain active agents classified as carcinogenic, mutagenic or reprotoxic long after administration (Easty et al., 2015; ETUI, 2022).

Many facilities still use thin plastic liners, cardboard boxes or open-top sharps containers without seals or vapour barriers to collect waste. Evidence-based guidelines call for sharps to be placed in rigid, leak-proof containers, and for soft waste to be collected in leak-proof, tear-resistant bins with foot pedal lids that lock automatically (Easty et al., 2015). Guidance reports note that hospitals continue to use waste receptacles that do not meet these requirements; when containers are overfilled or compacted, cytotoxic compounds can be released through aerosolisation or leakage, underscoring the need for compliant, sealable waste systems (HSE, 2023; Capoor & Bhowmik, 2017).

Contamination is healthcare settings is widespread, so waste must remain in a sealed environment where possible to minimise further contamination and exposure. Environmental monitoring demonstrates that contamination extends well beyond preparation areas. Wipe sampling studies in Swedish and German hospitals detected antineoplastic drug residues on

drug packaging, preparation surfaces and floors outside compounding units (Hedmer et al., 2005; Böhlandt & Schierl, 2016). In Montréal hospitals, 60% of surfaces cleaned by sanitation personnel contained at least one antineoplastic drug, with the highest concentrations on toilet floors, perfusion pumps and waste bin covers (Labrèche et al., 2021). Monitoring programmes also found contamination on waste room floors, bin exteriors and workers' gloves, indicating that hazardous residues persist despite routine cleaning (Hedmer & Wohlfart, 2012).

Evaluations of hermetically sealed waste management systems show they produce markedly lower vapour or microbial emissions than conventional open bins. A comparative study of automated hermetically sealed versus conventional waste systems recorded a 49.3% reduction in mean colony-forming unit counts around sealed units, suggesting improved hygiene and infection control (Britzelli & Aziz, 2024).

Similarly, studies comparing closed fluid waste systems with traditional canister-based collection in operating theatres found that closed systems significantly reduce contamination risks and are preferred by staff for safety and usability (Horn et al., 2015).

Porters, domestic staff, laundry workers and waste handlers, often lacking training in cytotoxic safety, regularly handle contaminated materials during waste collection and transport. Field studies confirm that sanitation personnel have measurable dermal contamination and work in environments where surfaces retain antineoplastic drug residues, yet they typically have less access to protective equipment and training (Labrèche et al., 2021).

In Sweden, the Regional Cancer Centre West's (RCC Väst's) cytotoxic safety programme highlights sealed waste-management systems as a necessary protective measure to reduce surface contamination and occupational exposure among nurses, pharmacists, porters and cleaning staff (Dahl & Delin Eriksson, 2014). RCC Väst's findings are based on real-world monitoring in Swedish hospitals and show that increased training and structured risk-assessment processes improve adherence to safe handling routines, strengthen organisational risk awareness and reduce contamination risks. The programme reinforces that hermetically sealed, vapour-tight waste systems are a critical component of preventing exposure across all staff groups involved in the HMP waste pathway.

Reviews of waste management practices stress that standardised procedures, comprehensive training and regulatory infrastructure are needed to protect all workers handling HMP waste (Capoor & Bhowmik, 2017). UK guidance reiterates that employers must provide appropriate PPE, risk assessments and health surveillance for everyone who may contact contaminated waste, recognising that HMP waste remains biologically active and hazardous long after administration (HSE, 2023).

2c. Taxonomy of HMP Waste

HMP waste can be grouped into solid and fluid streams, each presenting distinct containment challenges.

Solid waste includes IV tubing, syringes, vials, wipes, masks, gloves, gowns and sharps. Surface contamination may occur both inside and on the exterior of these items; wipe sampling studies have detected antineoplastic drug residues on primary packaging, preparation surfaces and high-touch objects in circulation spaces (Hedmer et al., 2005; Hon et al., 2013; Labrèche et al., 2021; Böhlandt & Schierl, 2016).

Fluid waste comprises infusates, irrigation fluids and patient excreta (urine, vomit, faeces, sweat and wound drainage). These fluids may contain unmetabolised drug and active metabolites for several days after administration. Fluid waste is particularly hazardous because of its fluidity and volatility; splashing, leaking and aerosolisation can occur during suctioning, toileting, flushing and cleaning, exposing healthcare workers, domestic staff and family members. When fluid waste saturates PPE or mixes with solid waste in soft liners, wicking through bag walls or leakage during transport becomes more likely, emphasising the importance of sealed, leak-proof waste systems (Easty et al., 2015; Capoor & Bhowmik, 2017).

Mechanical hazards such as broken glass or sharps can puncture liners and cause percutaneous injuries, underscoring the need for puncture-resistant, leak-proof containers (Capoor & Bhowmik, 2017; Easty et al., 2015).

Co-mingling of solid and liquid waste adds complexity: a punctured IV bag leaking into a liner can contaminate multiple items and increase the risk of leaks during transport (Cancer Council Australia, 2013; Capoor & Bhowmik, 2017).

Waste volumes vary by drug, dose, care setting and frequency of treatment. High-throughput oncology units generate large quantities of both solid and fluid waste each week, while home-based regimens produce smaller volumes but often lack purpose-designed infrastructure for safe collection and disposal.

2d. Limitations of Traditional Disposal Systems

Traditional disposal systems such as open bins, cardboard boxes and thin plastic liners lack puncture resistance, airtight seals and vapour containment. They often rely on manual closure practices that have repeatedly proven insufficient (Böhlandt & Schierl, 2016). Time-series studies and environmental monitoring have measured vapour escape, surface contamination and drug transfer to workers' gloves from such containers, even when they are not visibly overfilled (Hon et al., 2013; Labrèche et al., 2021).

Poorly sealed containers may rupture during transfer, leak during storage or release vapours in waste-treatment facilities, creating secondary exposure for transport operators and incineration staff. Such failures contravene the hierarchy of control, which prioritises engineered containment at every stage of the HMP lifecycle, and underscore the need for sealed, puncture-resistant and vapour-tight disposal systems. This form of waste disposal remains the weakest and least protected stage in the HMP life cycle.

PPE Waste from a German hospital

3. Regulatory Landscape: Legal Framework

The regulatory oversight of hazardous medicinal products (HMPs) is extensive. Across Europe and in other advanced jurisdictions, a convergence of EU directives, national legislation and international standards sets out requirements for closed-system handling throughout the HMP life cycle, including disposal.

3a. European Union Framework

HMPs are explicitly included within the Carcinogens, Mutagens and Reprotoxic Substances Directive (CMRD) following its amendment by Directive (EU) 2022/431. The CMRD makes closed-system handling a legal requirement for hazardous medicinal products across their entire lifecycle. Under the directive, employers must minimise worker exposure to CMR substances “as low as is technically possible,” and must use closed systems whenever the nature of the work allows. This obligation extends beyond preparation and administration to include waste handling and disposal.

In practical terms, this means that within the EU, sealed and engineered controls, including closed-system disposal devices (CSDDs), are now mandatory components of compliant HMP management.

EU guidance on safe management emphasises engineering controls and closed-system handling across the entire HMP life cycle. Sealed, clearly labelled containers at the point of waste generation are prioritised over administrative controls or reliance on personal protective equipment, in line with the hierarchy of controls. Within this framework, sealed and closed-system disposal devices are identified as an appropriate and effective method for managing cytotoxic and other HMP waste (Easty et al., 2015; ETUI, 2022).

3b. UK Requirements: COSHH and HSE

In the United Kingdom, the Control of Substances Hazardous to Health (COSHH) Regulations require employers to prevent or control exposure to hazardous substances “so far as is reasonably practicable.” Updated guidance from the Health and Safety Executive aligns closely with EU principles and identifies sealed containment as essential for cytotoxic and HMP waste. Such waste must be placed in clearly labelled, puncture-resistant, leak-proof containers that prevent vapour emission or environmental release (HSE, 2023; Easty et al., 2015).

Protection extends beyond clinical staff to porters, domestic workers and waste-handling personnel, all of whom require appropriate training and access to PPE and engineering controls. These requirements remain in force post-Brexit as part of retained UK health and safety law and are reflected in NHS procurement frameworks and occupational health policies.

3c. International Standards

International bodies mirror these requirements. The US National Institute for Occupational Safety and Health recommends that hazardous drug waste be collected in closed, puncture-resistant containers and warns that workers handling contaminated materials may be exposed through dermal contact, inhalation or ingestion (NIOSH, 2004).

The United States Pharmacopeia (USP <800>) mandates sealed, leak-proof containers that minimise vapour release or spill risk as part of compliant hazardous drug safety protocols (USP, 2023).

The International Society of Oncology Pharmacy Practitioners (ISOPP) similarly requires HMP waste to be sealed in vapour-barrier, puncture-proof containers immediately at the point of use, and places strong emphasis on comprehensive training and the use of closed-system devices (ISOPP, 2022).

Comparable principles are found in national guidelines from Canada, Australia and New Zealand, which mandate sealed containment systems, appropriate PPE and mandatory training for anyone handling cytotoxic drugs or associated waste (Department for Health and Ageing, 2015; Easty et al., 2015).

Sweden is a global leader when it comes to HMP disposal. Sweden's mandatory regulation *AFS 2005:5 – Cytostatika och andra läkemedel med bestående toxisk effekt* requires that cytotoxic waste be handled in closed, leak-proof and puncture-resistant containers that prevent the release of vapours or aerosols during routine use (Swedish Work Environment Authority, 2005). Although the regulation does not prescribe specific technologies, its exposure-minimisation obligations make hermetically sealed waste systems the most direct means of complying with national law across healthcare, pharmacy, veterinary and research environments. All of this data points to the same conclusion, that sealed, puncture-resistant and vapour tight containers for HMP waste are the best method for HMP disposal.

Similarly, the Swedish National Clinical Handbook specifies that cytotoxic waste must be placed immediately into sealed, leak-proof and puncture-resistant containers, noting that patient excreta may contain active cytotoxic residues for seven days or longer, requiring reliable hermetic containment at the point of disposal (Vårdhandboken, 2024). The guideline also requires that containers be locked, vapour-tight and compliant with ADR-S transport standards, with absorbent materials used for liquid waste and strict limits on fill levels and handling weight. These requirements reflect the need for airtight, mechanically secure waste systems that prevent leakage and vapour escape during routine clinical handling, transport and final disposal.

Hazardous waste disposal unit

4. Closed-System Disposal Devices (CSDDs): The Evidence-Based Solution

4a. Mechanisms and Design

Regulatory frameworks increasingly require the use of closed systems throughout the HMP lifecycle. Closed-system disposal devices (CSDDs) ensure that waste disposal remains sealed, capturing contaminated materials at the point of generation and preventing the escape of vapours, aerosols or liquids during handling, transfer and storage.

By isolating hazardous waste within hermetically sealed or vapour-resistant environments, CSDDs reduce occupational exposure, limit environmental contamination and support compliance with legal requirements for exposure minimisation (European Commission, 2022).

Safety guidelines emphasise that waste containers must be sealed and labelled at the point of generation and remain closed until final destruction, consistent with the hierarchy of controls that prioritises engineering solutions over administrative procedures or reliance on personal protective equipment (Easty et al., 2015; HSE, 2023).

In practice, closed-system waste solutions include mechanical heat-sealing bag units, rigid sealed containers and closed fluid-management systems, each adaptable to the type and volume of HMP waste.

1. Heat sealing bag units use continuous polymer liners that automatically fuse shut after each deposit, creating hermetically sealed waste capsules that prevent vapour escape, leakage and surface contamination, consistent with the white paper's definition of engineered containment that seals waste at the point of generation.

2. Airtight rigid containers provide tight, puncture resistant containment through compression sealed lids that remain sealed throughout handling and transport. Only when the lid remains closed is the exposure risk from hazardous waste contained.

Developing and implementing comprehensive closed-system protocols helps ensure consistent use and optimises staff safety in oncology and pharmacy environments (Meade, 2015).

Healthcare suppliers frequently describe their containers as "airtight," yet the term is often undefined and unverified in practice. For hazardous medicinal product waste, airtight sealing must be understood as a hermetic, vapour-tight closure that prevents the escape of contaminated air, droplets, aerosols or vapours under real handling conditions. This requires tested, automatic sealing at the point of waste generation and must not rely on manual tying, folding or snapping lids. Only systems that demonstrate verifiable vapour containment, leak prevention and independent validation should be described as airtight in a clinical context.

Technical data from the Pactosafe 4.0 systems shows how CSDDs achieve verified airtight containment through engineered sealing rather than manual closure. Both the stationary and mobile units use stainless steel housings, continuous polymer liners and controlled heat fusion to create hermetically sealed bags at the point of waste generation, preventing vapour or aerosol escape during handling (Technical Data Sheets, Pactosafe 4.0 Stationary and Mobile). Their drug-resistant materials, vapour tight inlets and automatic sealing functions remove

common failure points found in traditional bins and make them suitable for high-risk oncology and pharmacy settings and all areas where HMPs are prepared and administered.

Recent NHS Specialist Pharmacy Service (SPS) guidance reinforces the need for this level of protection at the waste stage. The *Guidance on Handling Cytotoxics in Clinical Areas* (Santillo et al., 2018) specifies that cytotoxic-contaminated waste must be placed immediately into appropriately labelled containers and that double-bagging may be required depending on local policy.

Crucially, the guidance notes that airtight waste-disposal systems specifically designed for cytotoxic, infectious and hazardous clinical waste can further minimise exposure by preventing aerosolisation, leakage and handling-related contamination. This supports the wider requirement for closed, sealed systems across the lifecycle of hazardous medicinal products, ensuring that waste disposal does not become a residual exposure point.

4b. Heat-Sealing Bag Units

Heat-sealing systems (mechanical heat-sealing units, continuous liners, airtight capsules) are recognised as effective technologies for managing cytotoxic and HMP waste. Devices using continuous polymer liners automatically seal the bag via heat fusion after each deposit, typically activated through foot pedal or motion sensor, to eliminate manual contact. This process creates hermetically sealed capsules that can be safely transported or incinerated without additional handling, reducing opportunities for vapour release.

Continuous-liner systems adjust to waste volume, reduce material consumption and eliminate the need for manual tying or double-bagging. In a UK oncology unit, replacing open bins with sealed heat-fusion units resulted in measurable reductions in surface contamination on waste containers and surrounding areas and significantly improved staff confidence in waste handling (Craig & Wadey, 2017).

Further evidence from Imperial College Healthcare NHS Trust supports the effectiveness of airtight heat-sealing systems in reducing cytotoxic exposure. The Hammersmith Hospital trial found that traditional 22 litre cytotoxic sharps bins, which open and close during treatment, allowed harmful vapours to escape and offer only a narrow waste aperture, increasing the chance of dermal or inhalation exposure (Imperial College Healthcare NHS 2016). Introducing an airtight sealing system eliminated these weaknesses. Nurses reported less odour around waste containers, no incidents of bag tearing and greater confidence in handling sealed waste, with training and daily use described as straightforward (Imperial College Healthcare NHS 2016). Following the trial, the unit adopted the airtight system across its chemotherapy day services.

This reinforces the broader finding that hermetically sealed, mechanically fused waste capsules reduce opportunities for vapour release, improve staff safety and offer a practical, reliable alternative to open or semi open cytotoxic bins.

4c. Airtight Rigid Containers

Rigid CSDDs are widely used in high-risk or high-volume areas such as infusion suites, pharmacy cleanrooms and operating theatres. Constructed from stainless steel or heavy-duty polymer, they incorporate gasketed lids, compression seals or locking mechanisms that ensure airtight closure and prevent vapour escape (Craig & Wadey, 2017). However, many products labelled as “airtight” may instead rely on manual opening and closing and do not

constitute airtight when in use at bedside. For a HMP container to be consider “airtight”, the unit must deliver hermetic, vapour-tight sealing, automatically at the point of waste generation.

Many designs include fill-level indicators or automatic lockout features to prevent overfilling, a common cause of spills and vapour release (Capoor & Bhowmik, 2017). Their structural durability provides puncture resistance for sharps, ampoules and high-density PPE loads, while wheeled bases allow safe movement through hospital corridors without compromising containment (Easty et al., 2015).

Implementation of sealed heat-fusion waste units in a UK oncology service eliminated manual tying, reduced contamination on waste-container surfaces, and received strongly positive safety and usability ratings from nursing staff (Craig & Wadey, 2017).

This study also identified exposure risks with this type of waste unit when used with HMPs, arguing that they are robust and sustainable but not adequate for eliminating exposure during everyday nursing use. (Craig & Wadey 2017).

4d. Closed Fluid Systems

Fluid waste represents an underestimated exposure pathway. The volatility and fluidity of cytotoxic fluids enable rapid dispersion through splashes and aerosols, especially during suctioning, flushing and sluice-room handling.

Closed fluid-management systems use fully sealed or direct-drain configurations, often integrating automated suction and inline filtration to collect cytotoxic fluids in vacuum-sealed canisters or discharge them through filtered lines under negative pressure.

These features prevent manual decanting and eliminate splashback, one of the most common causes of exposure during waste transfer and cleaning. Standards from the International Society of Oncology Pharmacy Practitioners specify that excreta and body fluids from patients treated with hazardous drugs should be handled using closed systems wherever possible; national guidelines from Australia and Canada echo these requirements (ISOPP, 2022; Department for Health and Ageing, 2015; Easty et al., 2015).

4e. Evidence of Efficacy

Evidence from the UK and multiple European settings consistently demonstrates that sealed and hermetically closed waste systems substantially reduce contamination compared with open or semi-sealed bins.

A Swedish comparative study found that hermetically sealed waste-management systems achieved a 49.3% reduction in mean microbial counts relative to conventional containers, indicating potential hygiene and infection-prevention benefits (Britzelli & Aziz, 2024).

A life-cycle and environmental assessment commissioned by Nuffield Health reported that continuous sealed waste systems reduced contamination risks and prevented leakage compared with traditional hospital waste bags, supporting their use within broader strategies to minimise occupational exposure and environmental release (Nuffield Health, 2023).

Vapour-containment assessments show that non-sealed containers can release detectable concentrations of hazardous drug vapours during liner changes or transport, whereas heat-sealed systems effectively eliminate detectable vapour leakage (Nisus Medical, 2014; Naimark & Erez, 2025).

Environmental monitoring conducted before and after the introduction of CSDDs has documented reduced contamination on waste-bin exteriors, adjacent surfaces and workers' gloves (Turci et al., 2010; Labrèche et al., 2021; Böhlandt & Schierl, 2016). Because sealing occurs at the point of waste generation, CSDDs also simplify classification, labelling and internal transport in line with institutional policies and guidance prioritising engineering controls (Capoor & Bhowmik, 2017; Department for Health and Ageing, 2015; ISOPP, 2022).
Independent evaluations in UK oncology units confirm that sealed waste systems reduce contamination and streamline logistics compared with traditional methods (Nuffield Health, 2023).

4f. Application Settings

CSDDs can be deployed across diverse healthcare environments. In high-throughput infusion centres and oncology wards, heat-sealing units and rigid sealed containers manage large waste volumes efficiently while minimising occupational exposure and odour. Smaller, portable systems increasingly support community and residential care settings administering oral or subcutaneous chemotherapy, providing safe waste collection without requiring complex infrastructure (Nuffield Health, 2023; Cancer Council Australia, 2013; Department for Health and Ageing, 2015).

In tertiary centres, integrating sealed disposal devices reduces background contamination that may interfere with cytotoxic drug assays and enhances staff safety (Turci et al., 2010).

Across all settings, evidence shows that CSDDs reduce surface and airborne contamination and simplify waste-management workflows, helping facilities meet national and international safety requirements.

4g. Strategic and Compliance Value

Beyond their engineering advantages, CSDDs function as both compliance tools and strategic investments in occupational safety. Their use aligns with legal requirements under the amended Carcinogens, Mutagens and Reprotoxic Substances Directive (Directive (EU) 2022/431), the UK Control of Substances Hazardous to Health (COSHH) Regulations, NIOSH guidance and multiple international standards, all of which aim to prevent exposure through engineered containment at source.

Sealed disposal units also strengthen traceability by enabling secure logging and tracking of waste from ward to incinerator, and support sustainability goals by reducing spills, rework and excess use of liners and PPE.

As oncology increasingly employs biologics, immunotherapies and antibody-drug conjugates, agents hazardous at low doses and capable of persisting in patient excreta, comprehensive containment becomes even more critical.

CSDDs therefore provide a scalable, evidence-based and legally compliant solution that aligns with the hierarchy of controls. Their adoption represents a minimum operational and ethical standard for protecting healthcare workers and ensuring that modern oncology operates within a zero-tolerance framework for occupational exposure.

5. Health & Safety Risks

Managing HMP waste remains a persistent source of occupational exposure in oncology, pharmacy and perioperative settings. Exposure occurs not only in specialist cancer units but also among non-oncology nurses who frequently handle cytotoxic drugs without adequate awareness or training. Even minor deviations from established procedures during waste disposal can create measurable surface contamination. To mitigate these risks, closed-system disposal devices (CSDDs) and other sealed waste technologies function as essential engineering controls within exposure-prevention programmes.

5a. Evidence of Exposure Reduction with CSDDs

Closed, sealed waste systems are associated with substantial reductions in occupational exposure to cytotoxic residues and infectious waste. In a multicentre Nuffield Health evaluation, surface wipe sampling detected agents such as cyclophosphamide and 5-fluorouracil on trays, telephones and keyboards at baseline; following deployment of Pactosafe sealed disposal units and closed-system transfer devices (CSTDs), contamination levels fell to trace or non-detectable levels across participating hospitals.
The intervention combined sealed, vapour-barrier units with structured training and standardised procedures in systemic anti-cancer therapy (SACT) services. Sites that adhered consistently to the protocol achieved near-zero contamination, while outlier sites were linked to documented process deviations.

Additionally, sealed waste units with CSTDs and training decreased contamination levels to trace or non-detectable in most sites. These findings indicate that CSDD implementation, combined with workforce education and routine audit, delivers measurable reductions in surface residues and exposure risk (Nuffield Health, 2023).

The programme also demonstrates the value of routine wipe-sampling as a feedback mechanism for exposure control. Consistent use of closed disposal and transfer devices localises contamination within sealed pathways and limits vapour and droplet spread into clinical work areas.

Department	Description Surface	PAC (ng/cm²)	ETO (ng/cm²)	DOX (ng/cm²)	CP (ng/cm²)	5FU (ng/cm²)	GEM (ng/cm²)	MTX (ng/cm²)	DOC (ng/cm²)	IP (ng/cm²)	CYT (ng/cm²)
Oncology Pharmacy	Bench	ND	ND	ND	ND	ND	0.001	ND	ND	ND	ND
Checking room	Bench	ND	ND	ND	0.006	ND	0.001	0.001	ND	ND	ND
Treatment room 7	Front three Baxter infusion pumps	ND	ND	ND	0.001	ND	0.02	ND	ND	ND	ND
Treatment rooms 5 + 6	Purple top two waste bins	ND	ND	ND	ND	ND	ND	ND	0.01	ND	ND
Waste room	Floor	ND	ND	ND	0.001	ND	0.005	ND	ND	0.01	ND
Checking room	Five yellow plastic over covers bags/syringes	ND	ND	ND	0.001	ND	ND	ND	ND	ND	ND
Pharmacy	Six yellow plastic over covers bags/syringes	ND	ND	ND	0.002	ND	ND	ND	ND	ND	ND
Pharmacy	Trolley	ND	ND	ND	ND	ND	ND	ND	ND	0.001	ND
Pharmacy	Yellow transport bag	ND	ND	ND	ND	ND	0.001	ND	ND	ND	ND
Clinical room	Bench	ND	ND	ND	0.006	ND	0.002	ND	ND	0.001	ND
Administration	Three trolleys	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Clinical room	Five blue trays	ND	ND	ND	4.33	0.40	ND	ND	ND	ND	ND
Administration	Floor patient toilet	ND	ND	ND	ND	ND	0.04	ND	ND	ND	0.004
Administration	Bench	ND	ND	ND	0.001	ND	0.01	ND	ND	ND	0.006
Administration	Five blue trays	ND	ND	ND	ND	0.21	ND	ND	ND	ND	ND
Administration	Front four Fresenius infusion pumps	ND	ND	ND	0.003	ND	0.004	ND	ND	0.06	0.06
Pharmacy	Bench	ND	ND	ND	0.001	ND	0.01	ND	ND	ND	ND
Pharmacy	Five blue trays	ND	ND	ND	ND	ND	ND	ND	ND	0.001	ND
Administration	Purple top waste bin + tray	ND	ND	ND	ND	0.36	ND	ND	ND	ND	ND
Administration	Floor patient toilet (cleaned)	ND	ND	ND	ND	ND	0.01	0.002	ND	0.08	ND
Administration	Two white + three blue trays	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Administration	Front two Smiths + two Fresenius infusion pumps	ND	ND	ND	0.04	ND	ND	ND	ND	ND	ND
Pharmacy	Bench	ND	ND	ND	ND	ND	0.002	ND	ND	ND	ND
Pharmacy	Yellow transport bag	ND	ND	ND	ND	ND	0.003	ND	ND	ND	ND

TH-1	3 Infusion pumps	3087	100	ND	ND	ND	ND	ND	ND	0.004	ND	ND
TH-2	Nursing work surface	1600	100	ND	ND	ND	ND	ND	0.99	ND	ND	ND
TH-3	4 Trays	1244	100	5.80	ND	ND	ND	ND	312	ND	ND	ND
TH-4	Pharmacy work surface	1600	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
TH-5	2 Transport bags	9904	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
TH-6	Pharmacy keyboard + phone	1000	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
CB-1	3 Infusion pumps	3087	100	ND	ND	ND	ND	ND	ND	ND	ND	ND

Results of Nuffield Health study showing exposure of Cyclophosphamide, 5-fluoruracil on clinical trays. Trace elements of cyclophosphamide, 5-flurouracil, Mitoxantrone, cytarabine and iphosphamide.

Description Surface	Surface Area (cm^2)	Total Volume (ml)	CP	CYT	DOC	DOX	ETO	5FU	GEM	MTX	PAC
3 Infusion pumps	3087	100	ND	ND	0.11	ND	ND	ND	ND	ND	ND
2 Nurse trolley tops	3108	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
4 Trays	1236	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pharmacy preparation area	1600	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
3 I-pads	213	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
Blood pressure machine	308	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
3 Infusion pumps	3087	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nurse work surface	1600	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
4 Trays	1236	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pharmacy work surface	1600	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
2 Keyboards + 2 I-pads	1428	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
2 Blood pressure machines	616	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
3 Infusion pumps	3087	100	ND	ND	ND	ND	ND	ND	ND	ND	0.06
Nurse work surface	1600	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
2 Nurse trays + 2 pharmacy trays	1236	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pharmacy work surface	1600	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
2 Transport bags	9904	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
2 Keyboards + 2 I-pads	1428	100	ND	ND	ND	ND	ND	ND	ND	ND	ND

Description Surface	Surface Area (cm^2)	Total Volume (ml)	CP	CYT	DOC	DOX	ETO	5FU	GEM	MTX	PAC
3 Infusion pumps	3087	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nurse work top	1600	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
5 Trays	4160	100	ND	ND	ND	ND	ND	0.09	ND	ND	ND
Pharmacy work surface	1600	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
3 Transport boxes	1920	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
3 Keyboards	1560	100	ND	ND	ND	ND	ND	ND	ND	ND	0.25
3 Infusion pumps	3087	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nurse work surface	1600	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
4 Trays	1236	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pharmacy work surface	1600	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dynamap	308	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
3 Keyboards	1935	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
3 Infusion pumps	3087	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nursing work top	1600	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
2 Pharmacy trays + 2 nurse trays	1236	100	ND	ND	ND	ND	ND	0.04	ND	ND	ND
Pharmacy work top	1600	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
2 Transport bags	9904	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
Keyboard and 2 I-pads	787	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
3 Infusion pumps	3087	100	0.06	ND	ND	ND	ND	0.09	ND	ND	ND
Nurse work surface	1600	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
4 trays	1236	100	0.17	ND	ND	ND	ND	0.34	ND	ND	ND
Pharmacy work surface	1600	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
Keyboard and 2 I-pads	787	100	ND	ND	ND	ND	ND	ND	ND	ND	ND
4 Door handles	96	100	ND	ND	ND	ND	ND	ND	ND	ND	ND

Trace levels of HMPs significantly reduced.
Where there was higher levels of exposure (Amber) this was due to not following prescribed process changes, not due to failure from the technology.

5b. Comparative Studies: Open vs. Closed Waste Systems

Operating theatre data further reinforces the containment advantages of closed systems. In a comparative study covering 30 surgical procedures in arthroscopy, urology and orthopaedics, the Neptune 2 closed system reduced potential exposure opportunities by up to 40% in arthroscopy and 25% in urology relative to open-canister systems (Horn et al., 2015).

No hazardous splash or spill-related exposure events occurred with the closed system, compared with three such incidents, including clothing contamination and fluid spills, under open-canister conditions (Horn et al., 2015). The closed system also required 3.5 times less staff time for set-up, maintenance and disposal, significantly reducing contact points with contaminated surfaces.

Additional benefits included substantial ergonomic and environmental gains: near-elimination of manual handling of full canisters, a reduction in landfill waste from approximately 40 kg to around 2.4 kg per equivalent case, and automated transfer through sealed docking and wash cycles (Horn et al., 2015).

Perioperative staff feedback aligned with these findings. Survey responses from 30 theatre staff indicated a 90% satisfaction rate for the closed system compared with 60% for the open system, with higher ratings for safety, usability and reliability (Horn et al., 2015). Closed, sealed waste systems are essential engineering controls, not merely optional extras.

UK evaluations also show that airtight waste sealing units materially reduce contamination and improve staff confidence. At the Kent Oncology Centre, a three-month trial reported reduced vapour and surface exposure and led to permanent adoption across the directorate (Maidstone and Tonbridge Wells NHS Trust 2018). Imperial College Healthcare NHS Trust found similar benefits, with nurses reporting less odour, no spillage concerns and straightforward operation, prompting full implementation in chemotherapy day units (Imperial College 2016).

Overall, the containment delivered by closed systems reduces exposure and cross-contamination risk while improving workflow efficiency and lowering environmental burden.

6. Operational Ease and Practical Usability

Closed-system disposal devices (CSDDs) must work effectively in real clinical environments, not just in theory. In Sweden, a leading oncology educator, underlines three core requirements for safe cytotoxic handling in clinical practice: minimising occupational exposure, using sealed and engineered containment systems, and ensuring that all staff involved in cytotoxic waste handling, including cleaners and transport personnel, receive appropriate training (Degerfält et al., 2024).

Evidence from oncology, perioperative and general hospital settings shows that CSDDs are easy to use, require minimal training, and integrate smoothly into established waste-handling routines. Staff consistently report reduced workload, fewer handling steps and improved confidence in safety, demonstrating that operational practicality is a central reason for their successful adoption (Craig & Wadey, 2017; Horn et al., 2015; Nuffield Health, 2023; Imperial College Healthcare NHS 2016).

6a. Staff Training and Workflow Integration

CSDDs are designed for simple, single-step operation, making them straightforward for clinical and non-clinical staff to learn. Studies in oncology and perioperative settings show that short orientation sessions of around 15–20 minutes are sufficient for staff to become competent with heat-sealing units, rigid sealed containers and closed fluid systems. Training can be delivered during routine shifts without disrupting patient care, and full clinical activity is maintained during implementation.

In Sweden, the national Lära Nära competency programme incorporates cytotoxic-handling modules that cover sealed waste handling, closed-system disposal principles, safe management of excreta and spills, and measures to prevent surface contamination (LäraNära AB, 2024). These digital, competency-based courses are used across Swedish healthcare settings, indicating that sealed and engineered containment practices are now embedded in standard nurse education and onboarding rather than restricted to individual hospitals.

Evidence on downstream workers highlights why this simplicity matters. Porters, domestic staff and waste handlers frequently come into contact with contaminated materials yet often receive limited cytotoxic-specific training, underscoring the importance of technologies that are intuitive and safe for all staff groups to operate (Capoor & Bhowmik, 2017; Labrèche et al., 2021).

Integrating CSDDs into existing workflows is also uncomplicated. Hospitals typically install sealed units at the same disposal points used for traditional bins, enabling staff to maintain established movement patterns while benefiting from improved containment. Point-of-use placement near care activities reduces unnecessary transport of contaminated materials and minimises opportunities for environmental contamination, consistent with exposure-prevention guidance and the hierarchy of controls. Multi-site evaluations report that when CSDDs replace open bins without altering disposal locations, compliance and uptake rates exceed 95% within the first month of deployment (Nuffield Health, 2023; Craig & Wadey, 2017; Imperial 2016).

6b. Process Simplification and Error Reduction

Traditional cytotoxic waste disposal relies on several manual steps, such as inserting liners, tying bags, double-bagging and hand-carrying waste through clinical spaces. These procedures are repeatedly identified as error-prone and associated with vapour release, spills and glove contamination (Capoor & Bhowmik, 2017).

Time-series and environmental monitoring studies show that manually tied bags often fail to provide adequate vapour containment, with persistent emissions and surface contamination detected even when containers are not visibly overfilled (Labrèche et al., 2021).

CSDDs remove many of these failure points. Heat-sealed continuous liner systems eliminate manual tying entirely and create hermetically sealed waste capsules after each deposit. Continuous liners automatically adjust to waste volume while maintaining containment, addressing the over- and under-sizing problems reported with conventional bags and liner systems (Craig & Wadey, 2017; Hedmer & Wohlfart, 2012). Rigid sealed containers reduce the risk of punctures, overfilling and leaks, and are designed to withstand sharps and heavy PPE loads without compromising integrity (Capoor & Bhowmik, 2017)

Closed fluid systems eliminate manual decanting, one of the most common causes of splash exposure, and allow surgical and perioperative teams to handle cytotoxic fluids within sealed pathways. By simplifying waste-handling steps and engineering out manual, high-risk actions, CSDDs significantly reduce opportunities for staff contact with contaminated materials.

6c. Operational Efficiency and Staff Acceptance

Facilities using CSDDs report reductions in waste-handling time and fewer interruptions to clinical activity. In perioperative environments, closed fluid systems such as Neptune 2 have been shown to cut the staff time required for set-up, maintenance and disposal by more than threefold compared with open-canister systems, while also reducing opportunities for exposure and manual handling of full containers.

Continuous-liner systems can store sealed waste for extended periods without odour or vapour concerns, providing flexibility in waste collection schedules and easing demands on portering services.

Staff acceptance of CSDDs is consistently high. In both oncology and theatre settings, workers rate sealed systems as easier to use, more reliable and significantly safer than traditional methods, with reported satisfaction levels around 90% for closed systems versus approximately 60% for open systems in perioperative studies. Users report reduced anxiety around contamination risks and greater confidence that waste is securely contained, which reinforces consistent use and long-term adherence to safe waste-handling practices (Horn et al., 2015; Craig & Wadey, 2017; Nuffield Health, 2023).

Sahlgrenska University Hospital's *Procedure for the Handling of Cytostatic and Cytotoxic Drugs* designates PactoSafe sealed waste units as the approved method for capturing cytotoxic waste at the point of generation (Västra Götaland Region, 2024). By embedding these hermetically sealed, vapour-tight systems directly into its standard operating routine, one of Europe's largest university hospitals demonstrates that airtight, independently validated containment is already established best practice for hazardous medicinal product waste. This

reinforces the wider shift across European healthcare toward engineered, sealed disposal systems that prevent vapour escape, leakage and secondary contamination.

6d. User Satisfaction and Time Efficiency

Frontline healthcare worker acceptance is a critical determinant of successful CSDD implementation. Technologies that are perceived as difficult, time-consuming or impractical tend to have low compliance, whereas systems that demonstrably reduce physical burden, simplify workflows and improve safety achieve sustained, long-term use (Craig & Wadey, 2017; Horn et al., 2015).

Evidence from oncology and perioperative environments shows consistently high levels of user satisfaction with closed-system disposal devices compared with traditional open systems.

Multi-Dimensional Assessment

Studies examining ease of use, safety perceptions, ergonomics, reliability and workflow impact consistently find that closed-system disposal technologies are preferred by staff. In both oncology and perioperative settings, users report that sealed, vapour-resistant units reduce handling steps, minimise spills and lower contamination on work surfaces and PPE, reinforcing adherence to safety protocols and increasing confidence in everyday practice.

Comparative studies further highlight these advantages. Perioperative staff express strong preference for closed systems due to fewer exposure opportunities, simplified set-up and disposal, and reduced manual handling demands (Horn et al., 2015).

Closed systems also offer ergonomic benefits and, in some implementations, reductions in overall waste volume, contributing to safer and more efficient clinical practice (Easty et al., 2015).

Staff preference for sealed systems is also consistent with wider evidence showing that dermal contact with contaminated surfaces is the principal occupational exposure route for hazardous drugs, making reliable containment a key contributor to perceived safety (Beigzadeh et al., 2025).

Sustained Usability

Evidence indicates that positive user response to CSDDs is durable rather than temporary. At the Kent Oncology Centre, initial evaluations led directly to permanent adoption, with super-users supporting ongoing competency and the system becoming embedded in routine workflows (Craig & Wadey, 2017).

Multi-site UK evaluations of sealed-waste systems similarly show strong, sustained compliance: once initial training and retraining had been completed, contamination levels remained low and staff maintained high adherence over repeated monitoring cycles (Nuffield Health, 2023). Combined, these findings demonstrate that CSDDs integrate successfully into institutional practice and continue to meet user expectations over time.

Quantitative Measurement

Improved time efficiency is consistently identified as an operational benefit of CSDDs. Studies show that sealed systems reduce the number of manual handling steps, remove the need for repeated mid-procedure interventions and streamline end-of-case waste disposal. These improvements translate into faster room turnover, fewer workflow interruptions and reduced

workload during high-pressure periods such as chemotherapy administration or perioperative changeovers.

Self-reported data from oncology units and structured time-motion observations from perioperative environments align in showing that closed systems reduce overall process time, smooth staff effort across procedures and minimise spill-related clean-ups. Broader facility-level evaluations also find that sealed waste systems reduce internal waste-transport burden, easing congestion and allowing uninterrupted clinical activity, particularly in high-throughput environments (Britzelli & Aziz, 2024).

Together, this evidence demonstrates that CSDDs provide meaningful productivity and efficiency gains alongside improved safety.

7. Environmental & Sustainability Impact

Environmental performance has become a central consideration in healthcare waste management, particularly as hospitals move toward circular-economy and carbon-reduction strategies. The strongest available lifecycle evidence shows that closed, reusable systems can significantly reduce greenhouse gas emissions and plastic use when compared with open or single-use disposal technologies.

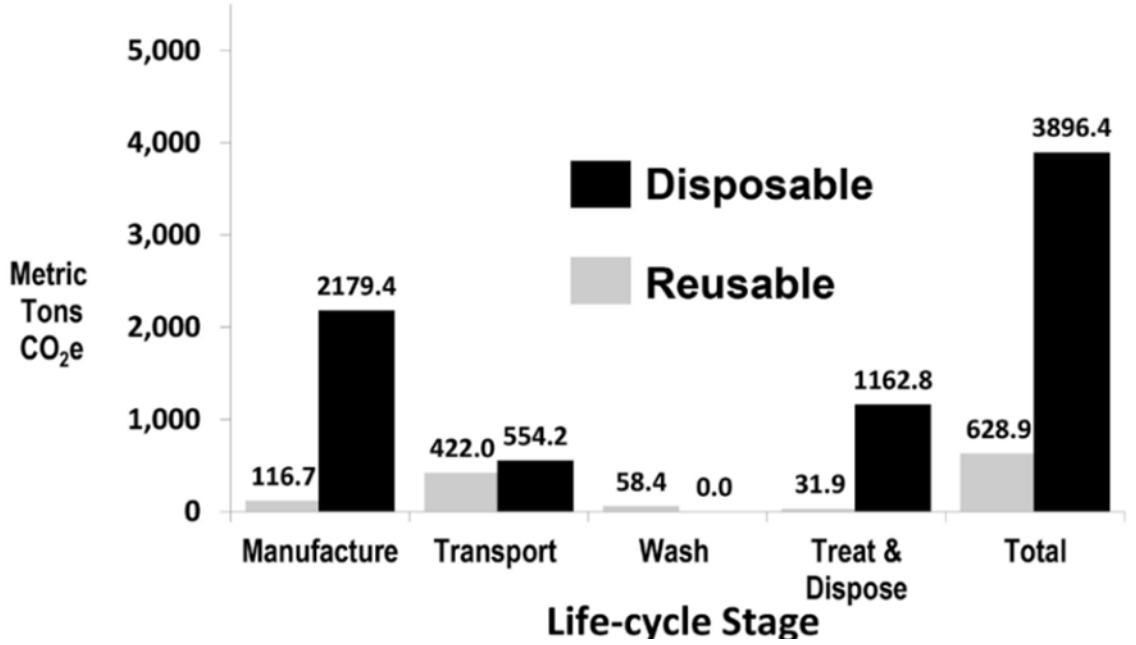
7.1 Lifecycle Assessments of Closed vs. Open Disposal

Life Cycle Assessment (LCA) studies consistently demonstrate that sustainable containment systems offer major environmental advantages by eliminating repeated container manufacturing and reducing transport and treatment impacts.

A US hospital converting from single-use to reusable sharps containers achieved an 83.5% reduction in greenhouse gas emissions, avoiding approximately 127 tonnes of CO_2 annually and diverting more than 30 tonnes of plastic and 5 tonnes of cardboard from landfill (Grimmond & Reiner, 2012).

These findings are reproduced at scale. A multicentre study across 40 NHS Trusts found an 83.9% reduction in total global warming potential following the adoption of reusable sharps containers, eliminating 900.8 tonnes of plastic and 132.5 tonnes of cardboard each year (Grimmond et al., 2021). Emissions fell from 313.0 to 50.7 kg CO_2e per 1,000 fill-line litres, equating to more than 16,000 tonnes of CO_2 saved annually across NHS England (Grimmond et al., 2021).

In both of the examples provided, whilst this does offer applications in non-HMP environments, sharps containers remain unsuitable for cytotoxic, HMP waste as they still allow for HMP exposure risks.



Annual carbon footprint, broken down by life cycle stage, for single use and reusable sharps containers across 40 NHS trusts from Grimmond et al's study.

Even where transport distances were large, reusable systems still delivered substantial benefits: a major US health system achieved a 65.3% emissions reduction, removing over 50 tonnes of plastic waste each year despite long-haul transport to processing sites (McPherson et al., 2019).

Collectively, these studies demonstrate that replacing open, single-use containers with closed, reusable systems reduces greenhouse gas emissions by 65-84%, depending on operational context. This demonstrates that reusable sharps containers are excellent for non-HMP use but that they do not eliminate the risk of exposure from HMP use and are not comparable to airtight waste sealing units for cytotoxic waste.

7.2 Carbon Footprint, Plastic Use and Waste Reduction

Ten-year modelling from the NHS evaluation indicates that reusable sharps systems prevent the manufacture of approximately 17.5 million single-use containers, avoiding more than 9,000 tonnes of fossil-based plastic and 1,300 tonnes of cardboard (Grimmond et al., 2021). Across different hospital sizes, annual carbon savings range from several hundred to several thousand tonnes of CO_2.

Manufacturing dominates the environmental footprint of single-use containers, accounting for over half of lifecycle emissions. By contrast, reusable systems shift the footprint to washing and transport, which together represent a far smaller total emissions profile (Grimmond & Reiner, 2012).

Sealed-waste technologies evaluated in oncology units have also shown reductions in leakage, rework and waste-handling inefficiencies, which indirectly contribute to

environmental benefits by preventing spill clean-ups and avoiding unnecessary additional bag and PPE use (Nuffield Health, 2023).

While reusable sharps systems provide clear environmental benefits for non HMP waste, they must remain entirely separate from cytotoxic pathways. For HMP waste, airtight continuous liner and heat-sealed systems offer distinct advantages.

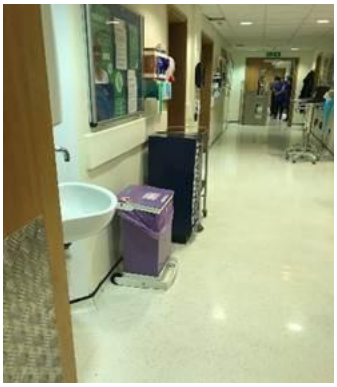
The Pactosafe evaluation shows that welded, air-sealed bags prevent vapour release and surface contamination, reducing accidental exposure and avoiding the leaks and overfilling issues that often lead to extra handling and clean up work. Each sealed bag holds more waste with less material than traditional sharps bins, lowering the volume sent for incineration and reducing fuel use and transport loads. Because the system is smaller, lighter and easier to move while still containing aerosols and residues, it helps limit unnecessary secondary bags, excess PPE use and other rework that increases the environmental footprint of cytotoxic waste disposal (Craig & Wadey 2017).

The Maidstone and Tonbridge Wells's NHS Trust's sustainability assessment also highlights the waste sealing unit as a key example of environmental improvement, noting lower raw material use, reduced transport emissions and fewer incinerated materials as direct results of replacing sharps bins with heat sealed liners (Maidstone and Tunbridge Wells NHS Trust 2018).

Feature	Traditional open systems	Reusable washout containers	Closed fluid systems	Mechanical heat-sealing waste units
Sealed containment	✗	✗	✓	✓
Vapour control	✗	✗	✓	✓ (no detectable vapour leakage)
Eliminate HMP exposure risk at the point of waste generation	✗	✗	✗	✓
Leak prevention	✗	✓	✓	✓
Puncture resistance	✗	✓	✗	✗
Prevents splash or aerosol spread	✗	✗	✓ (zero splash incidents reported)	✓
Reduces exposure events	✗	✗	✓ (up to 40% reduction in theatres)	✓
Automatic sealing or closure	✗	? (some provide lock mechanisms)	✓ (sealed suction paths)	✓
Minimises manual handling	✗	✗	✓ (threefold time reduction)	✓

Prevents overfilling	✗	? (reusable ones do, sharps bins can be overfilled)	✓	✓ (self-sizing liner)
Compatible with high volume waste	✗	✗	✓ (for fluid waste)	✓
Reduces carbon footprint	✗	✓ (about 84% lower with reusables – not applicable to sharps bins)	✓	✓ (about 82% lower per bag)
Reduces plastic use	✗	✓ (up to 900 tonnes saved annually across large systems – not applicable to sharps bins)	✓	✓
Reduces landfill waste	✗	✓	✓ (from 40 kilograms to about 2.4 kilograms per case)	✓
High staff satisfaction	✗	✓	✓	✓

Table showing the benefits and limitations of various waste disposal units



Traditional open waste systems

Non-airtight washout bin manufacturer products for cytotoxic waste

Examples of airtight heat-sealing systems are: Pactosafe & SealSafe, here in picture the Pactosafe

Neptune 2 airtight closed fluid system

Reusable washout bins for non-HMP Waste

Conclusion

Handling Hazardous Medicinal Product (HMP) waste represents one of the most persistent and preventable sources of occupational exposure to HMPs in European healthcare. Across oncology, pharmacy, perioperative care and ancillary services, the evidence is unequivocal: traditional waste-handling systems fail to provide adequate containment.

While clinical staff face clear contamination risks from HMP waste, exposure among sanitation workers, porters, laundry teams, waste handlers and ancillary care staff is often overlooked. These groups have the least access to specialist training despite some of the highest levels of routine exposure.

The regulatory environment clearly supports containment of HMP waste to reduce exposure. With the amendment of the EU Carcinogens, Mutagens and Reprotoxic Substances Directive (Directive (EU) 2022/431), closed-system handling is now a legal requirement throughout the entire lifecycle of hazardous medicinal products, including disposal. Similar expectations are reflected in UK COSHH regulations, USP <800>, ISOPP standards and national guidance from Sweden, Australia, Canada and other jurisdictions. The message is consistent: engineered containment at source is not optional, it is the minimum standard for compliance and for safeguarding workers.

A substantial body of evidence demonstrates that Closed System Disposal Devices (CSDDs) consistently reduce exposure to HMPs. CSDDs reduce contamination levels on waste containers, adjacent surfaces and PPE; eliminate high-risk manual steps such as tying bags or decanting fluids; lower the frequency and severity of spill or splash exposure events; and improve confidence, compliance and workflow safety among staff.

By contrast, open bins, semi-open bins, thin liners, reusable washout containers and manually tied bags do not adequately prevent leaks, vapour release, surface contamination and avoidable staff exposure in environments where HMPs are in use.

Environmental performance reinforces the case for transition. Lifecycle assessments from Europe and the United States show that reusable and closed-system containers reduce greenhouse gas emissions, eliminate thousands of tonnes of single-use plastic waste annually, and significantly cut cardboard consumption and transport burdens. Sealed continuous-liner technologies demonstrate similar reductions in material use and carbon intensity. These improvements align directly with Europe's commitments to sustainability, circular-economy principles and climate-resilient healthcare systems.

Although reusable washout containers offer strong environmental performance in non-HMP pathways, they do not address the fundamental exposure risks posed by cytotoxic and related hazardous medicines and should not be positioned as equivalent to airtight closed system disposal devices. These systems lack the capacity to create a physical barrier against aerosolised or volatile compounds and fall short of current occupational safety expectations.

The combined occupational health, regulatory and environmental evidence makes the limitations of traditional waste containers unmistakable. Open and semi-open bins, thin liners, and manually tied bags allow leaks, vapour release, surface contamination and avoidable staff exposure to HMPs. They fall short of both legal expectations and basic safety principles. Their continued use sustains preventable risks for nurses, pharmacists, cleaners, porters and waste handlers, while generating unnecessary plastic waste and avoidable carbon impact.

In contrast, closed-system disposal devices provide the containment performance that these other systems cannot. They are not an optional upgrade but the only approach that meets modern safety standards, fulfils regulatory duties and supports environmental objectives. Adopting closed systems is therefore an ethical responsibility to protect the workforce, a requirement under European law and a practical means of reducing the environmental footprint of healthcare waste.

Improving HMP waste management is both achievable and urgently necessary. By embedding closed-system technologies across oncology and all settings where cytotoxic or HMP waste is generated or handled, healthcare organisations can meaningfully reduce preventable harm, support safer working environments, meet legal obligations and deliver measurable sustainability gains.

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