Learning from accidents in waste management facilities

Lessons learned summary report

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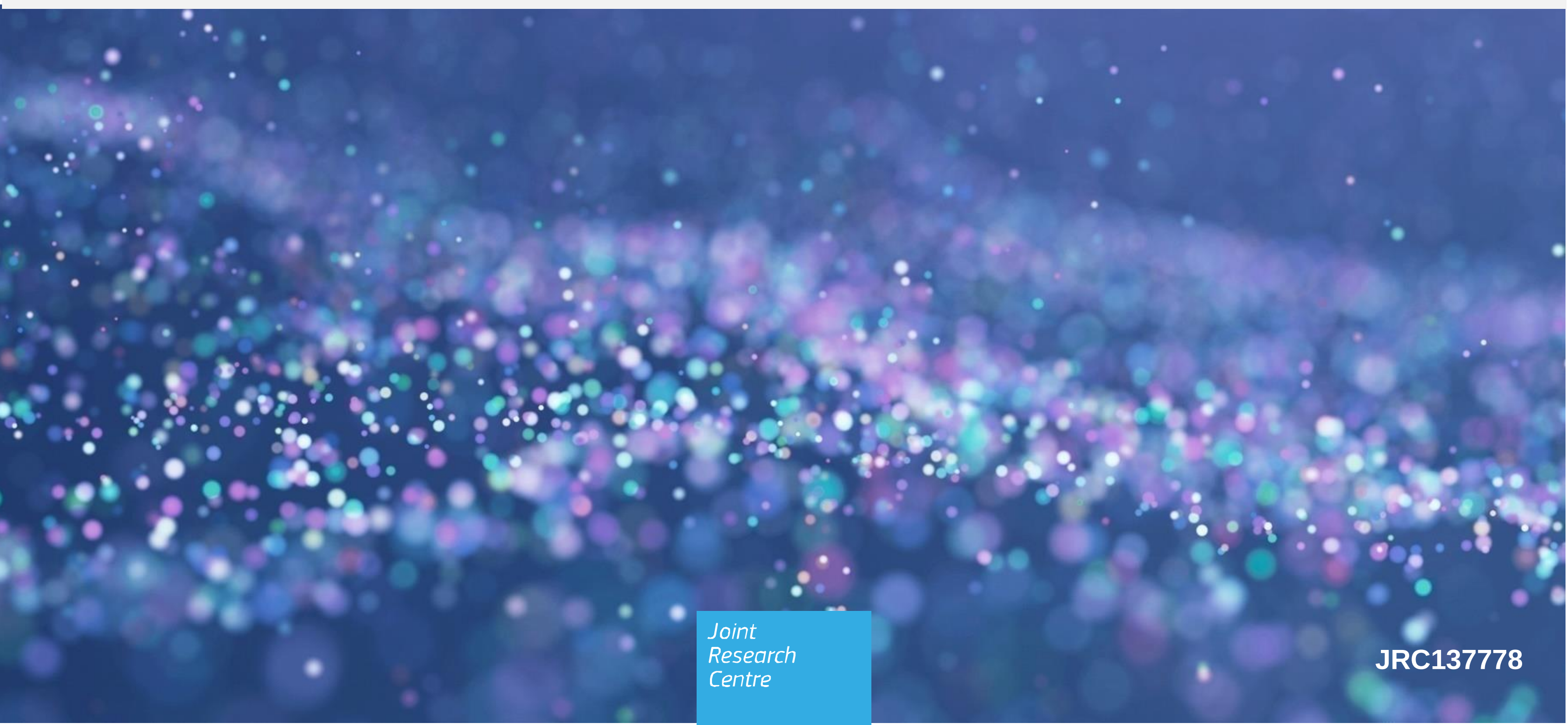

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Abstract

On 27 July 2021, seven workers died and 31 others were injured in the explosion of a tank farm for the disposal of chemical waste in Germany. Waste management sites have been the source of 15 major accidents occurring in the EU in the five years starting from 2018. They are the 5th most represented sector in the EU eMARS chemical accident database behind chemical, energy, mining and metals and explosive industries whose statistics are annually collected and analysed by the JRC. Therefore, to promote better prevention of incidents involving waste management in the EU and elsewhere, MAHB conducted a study of 85 chemical events in relevant facilities over the period 1989 – 2022 that were associated with the management of hazardous waste. The study is based on real incidents, reconstructing the accident descriptions, findings and lessons learned from accident reports available in open sources, especially the EU eMARS database but also several other international sources including the French ARIA database and the US Chemical Safety Board. The report includes 6 case studies taken from one or more of these sources that illustrate the most common lessons learned from all the incidents studied. The report also serves as a contribution to JRC collaboration on chemical accident lessons learned with the Organisation for Economic Cooperation and Development (OECD) and the United Nations Economic Commission for Europe (UNECE).

1 Introduction

Since the establishment of the first Seveso Directive in 1982 (82/501/EEC) [1], the Joint Research Centre's Major Accident Hazards Bureau (MAHB) [2] has consistently supported the European legislation aimed at prevention and mitigation of major accidents involving hazardous substances. The Seveso II Directive (96/82/EC) [3], which has been in effect since 1997, and currently the in-force Seveso III Directive (2012/18/EU) [4] continue to exemplify progressive industrial accident prevention measures. The Seveso III Directive is based on a performance-based framework, driven by the nature of substances involved, and employs a proportional risk-based approach. MAHB remains committed to adapting future policies and legislation to accommodate market-driven changes, including the introduction of new products and advancements in the chemical and petrochemical industries.

Under the Seveso Directive (2018/12/EU) the European Commission is required to disseminate lessons learned from major chemical accidents occurring to support industry operators and government regulators in chemical disaster risk management. To support this obligation, MAHB actively engages in conducting analyses that are subsequently disseminated through the Lessons Learned Bulletin (LLB) publication series. Moreover, MAHB collaborates with and leads expert groups on specialized subjects to enrich the understanding of industrial risk, refine strategies and enforcement tools employed by EU competent authorities to fulfil their obligations under the Seveso Directive. By fostering collaboration among stakeholders and sharing knowledge across industries, MAHB strives to enhance safety standards and mitigate risks associated with the handling and use of hazardous substances.

The LLB publication series serves as a tool for disseminating emerging and ongoing trends in chemical accident s and good practice for managing these risks. The LLB series serves as a valuable resource for policymakers, regulatory agencies, industry professionals, and the public, facilitating informed decision-making and promoting continuous improvement in chemical process safety measures. Each issue of the LLB focuses on a particular theme, identifying emerging risks and disseminating relevant prevention and mitigation measures. The report also serves as a contribution to JRC collaboration on chemical accident lessons learned with the Organisation for Economic Cooperation and Development (OECD) and the United Nations Economic Commission for Europe (UNECE).

This report is based on a recent JRC study of chemical incidents that took place in in facilities handling, storing, and processing hazardous waste across the EU and internationally, The report presents lessons learned from the incidents and also includes, suggested checklist questions for operators and inspectors of waste management facilities stemming from the study findings. The accident cases included in the study have been selected from accidents reported in the European Major Accident Reporting System (eMARS) and other chemical accident sources.

2 Learning from incidents in waste management facilities

On 27 July 2021, seven workers died and 31 others were injured in the explosion of a tank farm for the disposal of chemical waste in Germany. Waste management sites have been the source of 15 major accidents occurring in the EU in the five years starting from 2018. They are the 5th most represented sector in the EU eMARS chemical accident database behind chemical, energy, mining and metals and explosive industries whose statistics are annually collected and analysed by the JRC.

The French Bureau for Industrial Risks (BARPI) in their 2016 report, "Overview of accident statistics on waste management facilities" [5] states that "*the waste sector currently ranks as the 3rd most accident-prone industry*." The European Union (EU) generated a total of 2,135 million tonnes of waste in 2020, with 4.4% of that classified as hazardous waste (Source: Eurostat [6]). As the EU transitions to a more circular economy, the need to meet hazardous waste treatment goals is expected to increase. Coupled with the introduction of new types of waste associated with emerging technologies, such as the end-of-life batteries from electric vehicles, waste treatment facilities may be exposed to new chemical risks.

Therefore, to promote better prevention of incidents involving waste management in the EU and elsewhere, MAHB conducted a study of 85 chemical events in relevant facilities over the period 1989 – 2022 that were associated with the management of hazardous waste. The aim of this study was to identify typical failures, on both technical and organisational level, associated with accidents in these facilities. Although the focus of this study is on recipient waste management facilities, many of the good practices regarding operational procedures and organisational management are also relevant for regulators, waste producers, suppliers and consigners, and indeed some recommendations are directed specifically to these stakeholders.

2.1 Case studies and lessons learned

The following accidents and accompanying lessons learned have been selected as the most conclusive and information-critical across the 85 accident reports included in the JRC MAHB LLB study. The study highlights those accidents and lessons learned that the authors consider of most interest for this topic, with the limitation that full details of the accidents are often not available. In sum, the lessons learned are based on what can be deduced from the descriptions provided in the accident report. Notably, recurring patterns were identified across the 85 analysed cases through the causative analysis. These patterns indicated that the accidents reviewed for this study are broadly representative of a typical range of accident scenarios and lessons learned that can occur in waste management operations.

The accident descriptions and lessons learned from the following cases are reconstructed from the official accident reports. The report sequence of events, important findings and lessons learned are provided for each accident in the section following the description.

2.2 Case 1 – Toxic gas release during hazardous waste treatment

2.2.1 Sequence of events

A toxic gas release occurred from a reactor at a hazardous waste processing and recycling plant. The release was triggered when two employees used an acid waste solution containing hydrogen fluoride and nitric acid to remove deposits on the internal wall of the reactor. The reaction between the precipitate and the acid waste solution caused the generation of toxic gases, which escaped into the processing facility through an open sampling connection. The two shift employees noticed the gas leak and tried to stop the reaction by introducing neutralising lime into the vessel.

Despite wearing safety masks and receiving first aid, one of the employees succumbed to the gas exposure. The emergency services were promptly notified, and they alerted nearby residents to the accident through an emergency population warning and announcements made via vehicle speakers. Eventually, the release ceased because the reactor vessel was filled with water.

2.2.2 Important findings

- The true hazardous nature of the mixed acid waste was not recognised. Although classified as corrosive, its toxicity was underestimated due to misinterpretation of laboratory analysis and reliance on transport classification
- The site should have been classified as a Seveso site, but the waste classifications in the site's permit did not accurately reflect the actual properties of the waste treated at the site. Moreover, toxic gases generated by known hazardous reactions had not been taken into account when determining the scope of operations in the permit application
- Smaller gas leaks and odour nuisances had taken place previously. Precipitation in reactor vessels had caused problems during processing in the past
- The reactor vessel lacked automated functions, for detecting abnormal reactions and formation of toxic gas, as well as for triggering mitigation/shutdown procedures that would have helped to prevent or minimise a release
- The hazard of a toxic gas release during neutralisation had been identified in risk analyses but was never addressed
- Specified risk management measures were not followed as the employees' decision to use mixed acid waste to remove the precipitate was not a planned or authorised procedure, indicating a breakdown in proper protocols
- The rescue vehicle operators were not immediately able to locate the connection to the plant's water supply, resulting in a delay in a crucial element of the response
- Modifications made to the equipment over its lifespan were not adequately evaluated for their impact on risks or associated operating procedures, potentially introducing unforeseen hazards

2.2.3 Lessons learned

Acquire adequate information for waste classification

It is the responsibility of the operator to have a full understanding of all hazardous properties associated with waste handled on the site. Detailed hazard classification is critical for ensuring that storage, handling and disposal of the waste take account of the specific hazardous properties. As such, a site should not solely rely on transport documentation but have several measures in place that support proper hazard classification. As a starting point, there should be timely exchange between the operator and each waste producer on expectations regarding hazard classification of the waste to ensure that proper procedures are followed, and results are documented in detail and understood similarly.

Moreover, upon delivery, operators should verify that the hazardous properties and reactivity of waste chemicals have been analysed and identified, in as much detail as possible, in accordance with the EU's Classification, Labelling and Packing (CLP) Directive (Regulation (EC) No 1272/2008) or equivalent national system. While the CLP regulation does not apply to waste, the hazardous properties of waste chemicals must be known, and a hazard classification in accordance with the CLP regulation must be defined for them. The waste should remain in a separate handling area and not moved to processing until classifications are confirmed and documented. To this end, operators should have expertise on hand to interpret the results of chemical analyses, or to conduct additional analyses as may be required. Operators of waste producing and management sites should also consult relevant waste analysis and classification resources as indicated in Box 1.

Box 1. Waste analysis and classification resources

The following resources provide comprehensive guidance on how waste (one substance or streams of waste) should be classified and marked. The guidance describes basic concepts and references to available standards and methods regarding waste sampling and chemical analyses that should be done by the waste supplier to appropriately classify, label and document waste.

- The Directive 2008/98/EC on waste ('WFD') [7]
- The Commission Decision 2000/532/EC on the list of waste [8]
- The Commission notice on technical guidance on the classification of waste (2018/C 124/01) [9]

Focus on knowing the site hazards and assuring proper risk management

Hazardous waste sites must have absolute clarity on the type and degree of hazard of waste that they handle. There is a moral, if not a legal obligation, to manage chemical hazards responsibly to avoid chemical accidents that cause harm to individuals and the community. This obligation is particularly important for sites handling, recycling, treating, and storing hazardous chemicals. To fulfil this responsibility, an operator should calculate, as fairly as possible, the amounts of hazardous substances that will be handled on the site, the potential for loss of process control, and the range of possible chemical accident scenarios and their impacts. This information should be used to establish a site safety management system.

A proactive safety management system (SMS) would have prevented many of the mistakes that led to this case. For example, the system would have addressed risks identified in a hazard assessment with proper procedures and training and it would have defined a management of change procedure. It would have implemented an incident reporting and investigation process and encouraged a positive safety culture. Having failed to identify hazards and risks, the site precluded taking the steps to manage them and thus caused a fatal incident.

Ensure proper legal oversight and compliance

Moreover, in the EU and many other countries, many hazardous waste sites are designated as high hazard sites and therefore are legally obligated to meet regulatory obligations in managing their risks and receive heightened level of oversight from the government authorities. The permitting process should establish whether a site is high hazard (in the EU, a Seveso site) before the site is allowed to operate. For this purpose, the operator should have completed a process hazard identification, considering the full hazardous nature, potential reactions, and the overall risk profile of the hazardous waste expected to be handled on the site, and introduce the findings into the relevant permit application. (The type of permit may differ from country to country, but it is often a hazardous waste permit, environmental permit or equivalent.). Hazardous waste associations should contribute to building awareness about national requirements and competence for conducting the hazard identification process.

On their side, regulators should also have a standard process for identifying potential high hazard sites during the permitting process. Indeed, waste management site operators sometimes are not fully aware that their operations could qualify them as a high hazard site, and for this reason, it is particularly important that regulators can also independently identify potential candidates for this status. In this regard, there may be a need for periodic training or awareness campaigns for local authorities responsible for permitting.

There is also a responsibility on the side of the clients. Waste producers and regulators also have a role in ensuring that hazardous sites are operating within the proper legal framework. Producers should have identified the hazardous properties of their own waste, prior to delivery to the waste management site, and verify that their waste handlers are legally authorised to manage them.

Install automated safety instrumented functions (SIF)

Formation of toxic gases is common within vessels and reactors used in hazardous waste treatment. Operators should ensure that automated safety features are in place to enhance safety within processes involving hazardous substances and the potential formation of toxic gases. By providing early warnings on toxic gas formation and triggering automatic shutdown or mitigation procedures (i.e., automated injection of neutralising solution), these features reduce reliance on human intervention during unforeseen circumstances. Ph sensors or analysers should be connected to the basic process control system (BPCS) to avoid human interaction with the process vessel (via sampling for example as in this case as shown in Figure 2). Moreover, in processes where maintaining a certain pH level is critical for preventing hazardous chemical reactions, such as the waste neutralisation process, Ph monitoring can also be integrated into the safety instrumented system (SIS), to ensure that appropriate automated measures are triggered in case of process upset. Technical guidance outlining the necessary protocols and methodologies to be followed for the effective deployment of automated safety measures can be obtained from industry standards such as:

Figure 1. Sampling area of toxic gas release on the top of the waste treatment reactor

Source: Tukes, 2022, [10]

- ISA-84/IEC 61511 – Functional Safety: Safety Instrumented Systems for the Process Industry Sector
- IEC 62682:202- Management of Alarm Systems for the Process Industries
- IEC 61508 – Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems

Periodically update and test emergency plans

The difficulty in finding a suitable coupling during the emergency response highlights the need for meticulous emergency planning and preparedness. Regular drills, including scenario-based training, should be conducted to assess and validate emergency response capabilities as well as ensure the availability and optimal functionality of all safety functions and resources. This proactive approach ensures swift and effective response during critical situations.

Source: eMARS No. 001344 [11]

2.3 Case 2 – Fire in a hazardous waste storage facility at a treatment centre

2.3.1 Sequence of events

A fire broke out in an outdoor storage area of a hazardous waste treatment centre. The infrared alarm system triggered an immediate response from the on-site personnel. However, their attempts to extinguish the fire were hindered by the subsequent explosion of multiple aerosols. The emergency services were contacted and they extinguished the fire after about one hour. At least 11 tonnes of waste, including two tonnes of special household waste (SHW, also known as hazardous household waste, HHW) from waste collection centres, four tonnes of various packaging materials (pallets, crates, plastic containers, etc.) and five tonnes of rubber hoses were consumed by the fire. A plume of black smoke was released. However, measurements indicated no signs of toxicity associated with the smoke.

2.3.2 Important findings

- The fire originated from a stock of 60-litre plastic crates containing special household waste from waste collection centres, which had been delivered just before the weekend and had not yet been sorted
- The operator suspected that an exothermic reaction caused by the mixing of incompatible SHW may have been the cause of the fire
- The area used for storing unsorted waste, located at a distance from buildings, was not specifically considered in the site's hazard study, which did not include a fire scenario for this area. Also, the potential projection of aerosol cans was not taken into account, which could have caused a domino effect
- Different types of waste, including aerosol cans and hydraulic hoses, were stored together pending sorting. The presence of these items complicated internal intervention efforts by generating projectiles and heavy smoke, posing additional challenges for fire suppression

2.3.3 Lessons learned

Importance of fire detection.

The utilization of infrared detection equipment proved pivotal in the early identification of the fire outbreak. Smoke, heat, flame and ultraviolet (UV)/infrared (IR) detectors enable the prompt detection of fire hazards or outbreaks, allowing for timely response, potentially reducing the severity of accidents and enabling more efficient emergency interventions. Therefore, to enhance safety measures, the appropriate detectors should be installed in areas where inflammable hazardous waste is handled, including storage, pre-sorting, pre-acceptance, rejection, quarantine, and processing areas.

Implementing hazard and compatibility zoning.

Strategic zoning of areas based on the classification of hazardous waste could significantly reduce the risks associated with incompatible materials reacting with each other. Segregating hazardous waste based on compatibility ensures that incompatible waste is stored separately. This practice reduces the chance of accidental mixing or exposure to potential chemical ignition sources, thereby mitigating the risks of hazardous reactions. Storing wastes with similar health hazards separately also reduces the potential for cross-contamination and exposure to toxic or hazardous substances. Moreover, segregation allows for easier identification and management of hazardous materials during emergencies. Emergency responders can quickly assess the situation, identify the risks, and take appropriate actions to mitigate them. Segregation of hazardous waste should align with regulatory requirements, guidelines, and industry best practices.

Timely sorting and processing of hazardous waste.

Allowing hazardous waste to remain unsorted for extended periods increases the likelihood of accidents and incidents. Timely sorting and processing of hazardous waste mitigates the likelihood of exothermic reactions that may arise from the accumulation of unsorted waste. Accumulation of waste can occur due to various reasons including low operational activity, stemming from equipment or workforce downtime (i.e., holiday periods). Operators need to establish practices to address situations where unsorted waste exceeds the capability of the facility to handle the waste in a timely manner. For example, operators can request that delivery of waste be delayed, have subcontracting arrangements with other waste operators for handling excess volumes or in the worst case, refuse to accept the waste. Such practices require planning and procedures to support them and avoid last-minute decisions that inevitably result in the accumulation of hazardous waste beyond manageable levels.

Specific hazards associated with handling substances such as aerosols.

When handling hazardous substances like aerosols, it is essential to carry out comprehensive risk assessments that account for all operational conditions. These assessments should ensure that emergency plans are resilient and can effectively handle a wide array of potential scenarios, considering the type, variability, and quantities of waste present on-site. For instance, failing to consider a fire scenario in the unsorted hazardous waste area, coupled with the possibility of aerosol cans projecting, resulted in unexpected challenges during emergency response.

Source: ARIA No. 48274 [12]

2.4 Cases 3 & 4

2.4.1 Case 3 - Poisoning in a wastewater treatment plant during dumping-

2.4.1.1 Sequence of events

Following an erroneous transferring operation, a release of chlorine was reported at a wastewater treatment plant. The event started shortly after a tank truck driver started transferring bleach into an aluminium polychloride tank leading to the release of chlorine gas. The transferring operation was stopped and three site employees were hospitalised. An 80m safety perimeter was set up, and the facility's ventilation made it possible to evacuate the vapours via a chimney. Pedestrian traffic around the site boundaries was prohibited for several hours.

2.4.1.2 Important findings

- Mixing of incompatible products during transferring was attributed to a handling error. A technician indicated to the tank truck driver both by hand gestures and orally the specific transfer opening on the station's manifold

- The consignment documentation was not inspected and the transfer checklist indicated in site procedures, was prepared and completed without the necessary checks ever taking place prior to the acceptance of the tank truck into the facility and the commencement of transferring operations
- Wastewater plant employees involved in loading and unloading operations had not received the required training in classification, labelling and packaging protocols for dangerous goods transport (UN ADR)
- There were no procedures displayed in the transfer area
- Vessels were not equipped with the appropriate UN ADR dangerous goods signage

Source: *ARIA No. 37516* [13]

2.4.2 Case 4 – Poisoning in a wastewater treatment plant during dumping

2.4.2.1 Sequence of events

A release of chlorine took place at a waste incineration plant during transfer operations of hydrochloric acid (HCL) from a tank truck to the plant's acid tank. The driver connected the transfer hose to the two vessels and initiated the transfer. After 200 litres had been transferred, the employee responsible for accepting waste noticed a chlorine release stemming from the tank while monitoring the tank's filling level. He suspended the operation and sounded the alarm. Despite wearing individual protective gear (a cartridge mask), the driver felt faint but still managed to walk to safety beyond the transfer zone. Around 1,500 litres of HCL were fouled and no other impacts were reported.

2.4.2.2 Important findings

- The lorry was transporting three large, 1,000-litre bulk containers of acid and another one containing 10% sodium hypochlorite (NaClO) in a single compartment
- The bulk containers of HCl and NaClO were identical and relied on the same transfer couplings
- The driver had mistakenly hooked the plant's acid tank to the sodium hypochlorite bulk container, which had been intended for another client, and initiated the transfer
- The driver's mask was inefficient, as the cartridge had been used for several consecutive days

Source: *ARIA No. 43406* [14]

2.4.3 Lessons Learned Cases 3 & 4

Be informed about chemical hazards in loading and unloading and implement appropriate practices to manage the risks.

Waste management operators often ignore the full range of obligations that accompany the business of managing hazardous waste. Just as they need to handle, process and store waste safely on the site, they also have to manage the interface with transport. They need to comply with legal obligations associated with dangerous goods transport in loading and unloading operations. No transfer operation should be based solely on oral confirmation to initiate.

Moreover, the safety management system (SMS) must include the implementation of standardised procedures for reducing the risk of chemical release during loading and unloading operations. For example, staff should be trained on these procedures and they should be clearly posted in the transfer area as a quick reference for the driver and other personnel involved. An efficient SMS should also address the inspection and replacement of components on personal protective equipment, such as cartridges in masks, especially for personnel at risk of being exposed to toxic releases during waste handling and loading/unloading.

Particularly for the second case, loading of waste at the supplier's site should also take into account the consignment's delivery order. Pre-arranging and dividing the containers, that are appropriately labelled would minimise the risk of transferring the wrong consignment to the waste recipients. Additionally, dividing and compartmentalising the waste according to the delivery order would have significantly reduced the risk of delivery to the wrong recipient. Incorporating digitised logistics applications on both the waste supplier and treatment facility involving QR codes on waste containers and QR code scanning during waste acceptance can also reduce errors in waste deliveries.

Establish and enforce criteria and procedures for accepting waste into the facility

Operators should not only require, but actively enforce acceptance procedures. These procedures at minimum should require that waste conforms with documentation and that the documentation clearly specifies the hazardous type of the waste. Labelling of waste containers with prominent and standardised information (including the chemical name, concentration, hazard symbols, and any other relevant details) should also match the consignment documentation. Pre-acceptance should also include physical inspection of the waste and/or containers and packaging to verify consistency with the documentation and checking for any signs of damage, leakage, or anomalies. All records related to pre-acceptance should be maintained for cross-reference and verification purposes.

Ensure competency and certification of employees

Personnel involved in the carriage of hazardous waste, particularly in loading and unloading and in handling during deliveries. Both consigners (delivery personnel) and consignees (receiving personnel) should be required to have a minimum competence, documented appropriately, that certifies that they have been formally trained in safety management relative to the operations in which they are involved. For example, in the EU, a UN ADR certification should be required for anyone involved in loading and unloading operations with training updates at the recommended frequency. UN ADR training covers all areas of safe procedures, including loading and unloading and emergency response, but also legal requirements for documentation, classification, labelling and packaging of dangerous goods.

2.5 Case 5 – Incompatible mix at a hazardous waste treatment facility

2.5.1 Sequence of events

During transfer operations at a Seveso hazardous waste treatment facility, a yellowish smoke with a chlorine odour was released through the vents of a 30-m³ vertical tank. The incident occurred while an experienced technician was transferring 1,800 litres of a solution labelled as "acid" from three 1,000-liter containers. The operator initially sprinkled water on the tank and later neutralized the mixture with soda, followed by rinsing the tank. Several personnel experienced eye irritations, and approximately 125 individuals from the facility and adjacent firms were confined indoors for three hours.

2.5.2 Important findings

- The three 1,000-liter containers were mislabelled and misclassified as acids when they actually contained a sodium chlorite ($NaClO_2$)-based alkaline chemical product
- The misclassification and mislabelling were intentional, as a result of an agreement between the waste treatment facility sales representative and the waste producer, due to delays in obtaining a site acceptance certificate
- The technician had conducted a pH test on the incoming waste and measured a pH level of 9, but failed to notice the inconsistent labelling
- The preliminary waste analysis test conducted to verify compatibility was not representative of the reaction risks for the volumes introduced (100 ml extracted from the waste delivered for a tank containing 10 to 15 litres)
- The hazard analysis included risks related to mixing incompatible substances but not such large quantities
- Following the release, the operator sprinkled the tank causing the smoke to thicken

2.5.3 Lessons learned

Establish a robust waste analysis plan

A robust waste analysis plan should be in place to allow verification of hazardous waste against the documentation provided as well as adequate waste sampling. An operator must establish a comprehensive chemical and physical analysis of a representative sample of the waste. This information can be obtained through either the process of sampling and laboratory analysis or by relying on other relevant documentation.

Establish pre-acceptance procedures

It is essential that the operator has waste pre-acceptance procedures in place and responsible. The procedures should establish that only designated personnel can accept waste into the site and these personnel must be fully trained on the pre-acceptance procedures. Discrepancies against consignment documentation vs. the waste containers' labelling and the site's pre-acceptance sampling findings should be addressed before accepting the waste on-site. When the waste supplier has misclassified the waste, or where a representative sample has not (yet) been assessed, the waste should be held in a separate area, for a limited time period, until the true hazardous properties of the waste are determined.

Non-conforming waste should be kept in a separate monitored holding area with a clear time limit for resolving issues before the waste is refused, in order to minimise the site's exposure to potential reactive components or other unknown hazards. Thorough checks of the waste received and verification steps should be part of the waste acceptance procedures before initiating any transfer. An experienced supervisor should be reachable at all times by staff, in case there is any question regarding acceptance of a delivery. All personnel should be trained on these procedures. The holding area for waste prior to acceptance should be separate from any other waste, with appropriate safety conditions (e.g., temperature controls, separation distances from other waste), and instrumentation for monitoring the condition of the waste (including video cameras).

Incorporate strict waste rejection procedures

The pre-acceptance process should also include instructions on how to deal with non-conformance, depending on the type of conformance, and clear criteria for refusing waste delivery. In addition to procedures for dealing with misclassified waste, the instructions should also ensure that waste is rejected if the supplier has not alerted the operator to the hazardous waste properties in advance so that the operator can determine that the site has the competence and capacity to conduct treatment and disposal safely.

Connect quality assurance with waste supplier management

The study identified at least ten cases where waste suppliers were complicit in sending non-conforming/incompatible waste streams to waste treatment facilities. Such non-conformance could involve contaminated waste, mislabelled waste vessels, delivery of different waste than the one documented or the presence of other types of waste within the waste stream against consignment documents. Hence, waste rejection should be supported by a rigorous quality assurance (QA) and waste supplier management programme. This programme should be in place to facilitate documenting and analysing deviations from agreed-upon waste deliveries, fostering a culture of accountability and compliance within the waste management supply chain. Employees associated with waste acceptance and rejection should have access to this system and be able to provide relative information, particularly in cases where incoming waste is rejected. Generating Non-Conformance Reports (NCR) from the relative waste facility QA department plays a crucial role in eliminating the recurrence of incoming non-conforming waste.

Identify realistic accident scenarios and train on proper mitigation and response procedures

Waste management sites should understand the hazards and what could go wrong in a treatment or disposal process. This requirement means that a site needs to analyse the range of processes and the range of interactions that could go wrong, based on typical mistakes that can occur, such as an insufficient analysis of the dangerous properties of the waste. To this end, past events and near misses are an invaluable input. The site should investigate chemical incidents and near misses to adjust scenario information, identify mistakes, and incorporate the lessons learned in their safety management systems. Understanding scenarios, and typical sequences of events, that could lead to a dangerous incident is required for process hazardous analysis and worker training, in particular.

In this specific case, the operator decided to sprinkle the tank with water which resulted in a thickened smoke. This action could have led to even more serious impacts since chlorine gas can react with water creating hydrochloric acid which would precipitate near the tank. Instead, the site should have had a rigorous process to prevent mischaracterization of the waste, but they should also have identified the ways that the process could have gone wrong and trained the employees to react properly. Although the correct action was taken during the sequence of events, the operator could have omitted using water and directly applied the caustic soda to minimize the release effects. A safe response to this mistake could have been assured by training staff on how to respond to scenarios involving predictable malfunctions in the process.

Source: ARIA No. 42944 [15]

2.6 Case 6 - Fire in a battery storage cell at a waste site

End-of-life (EoL) batteries and fire hazards

An incident at a hazardous waste collection centre involving a fire in a container loaded with lead-acid batteries highlights the potential hazards and risks associated with the emerging use and disposal of batteries. The cause of the fire was auto-ignition inside the container due to overheating from contact between the terminals of the batteries. Cables that had been left connected to the batteries increased the risk of contact between the terminals. Following the event, the operator has been instructing waste suppliers to dismantle the battery cables before storing them in containers. The current study includes at least three cases in which batteries were either mishandled or not identified in the incoming waste streams. These incidents serve as a reminder of the critical issue of battery handling procedures and the need for updated protocols to mitigate the risk of fires.

Evolving waste management practices and emergency preparedness for EoL batteries

The incident emphasises the need for updated protocols in the handling and disposal of batteries to mitigate the risk of fires. Waste collection, treatment, recycling, and disposal centres should assess their current procedures regarding waste acceptance and pre-processing sorting, particularly as the volume and types of batteries in waste streams continue to rise. Waste management practices must evolve to include efficient sorting mechanisms to identify and handle various types and expected influx of incoming EoL batteries. Waste treatment operators may need to reassess a facility's' risk analysis, coordinate further with waste suppliers for proper waste sorting, and identify appropriate, and possibly new, treatment processes. Additionally, emergency planning and preparedness, particularly addressing EoL battery fires may need re-evaluation. EoL battery fires can lead to thermal runaway, where one battery pack overheats and ignites other cells, leading to an intense and prolonged fire, while releasing significant heat, toxic gases, and chemical fumes. To handle such incidents safely, firefighters require specialized training and equipment, while waste treatment sites may have to reassess their fire mitigating measures.

Directive 2006/66/EC and EoL battery disposal

Directive 2006/66/EC on batteries and accumulators and waste batteries and accumulators specifically implicates the battery producers, as well as end users, towards minimizing risks associated with handling batteries at the end of their life. The Directive emphasizes the importance of providing detailed information to end-users focusing through a labelling system, that provides transparent, reliable and clear information on the safe disposal of EoL batteries.

Source: *ARIA No. 43973* [16]

3 Accidents causation analysis

The causation analysis was conducted after an extensive review of available accident reports taking into account several prerequisites such as the industry type and availability of information within the accident reports. The following sources were used to extract relevant reports:

- Major Accident Reporting System – European Commission (eMARS)
- French Industrial Accidents Database - Bureau for Analysis of Industrial Risks and Pollutions (ARIA)
- German Central Reporting and Evaluation Center for Incidents and Malfunctions in Process Engineering Plants (ZEMA)
- United States Chemical Safety Board (CSB)
- Japanese Failure Knowledge Database (JFKD)
- Finnish Safety and Chemicals Agency (TUKES)

Notably, accident reports included within the study should have at minimum included the initiating event and at least one cause for the accident sequence. The accident reports were analysed individually to extract attributes relevant to lessons learned such as impacts, causes and underlying factors. Where information was available, additional attributes could be extracted, such as the classification of waste handled, the operational state of the facility when the accident sequence was initiated, as well as aggravating factors within the accident sequence.

The study took place taking into account 85 accident reports, limited to accidents occurring exclusively in dedicated waste management facilities, excluding interim waste storage or other activities within production sites. It primarily focuses on waste treatment, storage, and disposal facilities, with emphasis on the safe handling of chemical hazardous waste. Incidents related to municipal wastewater and sewage treatment are excluded unless the accident circumstances extend beyond these activities. Incidents involving non-hazardous waste facilities are considered if the substances involved became hazardous due to loss of containment.

The following section provides the study summary.

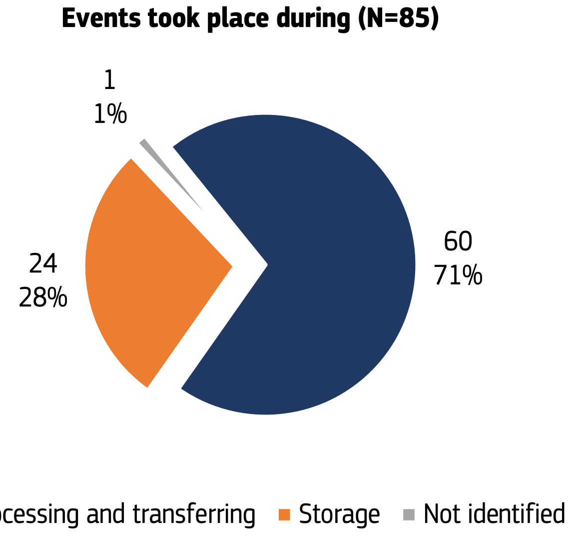
3.1 Classification of waste and operational state

The majority of the incidents studied took place in facilities handling strictly hazardous waste (68 cases or 80%), while in ten cases both hazardous and non-hazardous waste were involved. Only seven incidents (8%) were included from facilities that according to their permit were handling non-hazardous waste when it was determined that either:

- Hazardous waste was presence but was not identified within the handling streams, or
- The substances released due to fires or loss of containment involved hazardous substances

In many cases, it was possible to identify the operational state of the facility and when or where the incident sequence was initiated.

Figure 2. Waste management facility operational state



Source: JRC analysis, 2024

As shown in Figure 3, in 71% of the cases (60 cases), the events initiated during the processing and handling of the waste, whether that included treatment, pre-treatment, recovery or disposal. In at least half of those cases (33 cases) loading/unloading or transferring operations were underway when the accidents occurred. Hazardous waste under storage was also involved in over a quarter of the cases (28% or 24 cases), with the majority of those (14 cases) involving auto-ignition as poorly sorted incompatible waste streams were sent to storage.

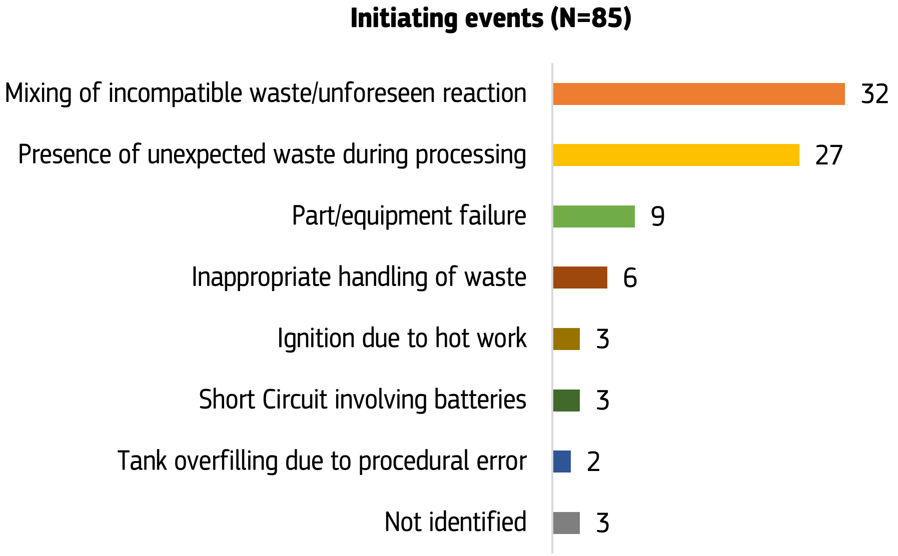
3.2 Impacts

According to the analysis, the events studied collectively resulted in at least 16 fatalities and more than 300 injuries worldwide since 1989. One of the most catastrophic events occurred in Leverkusen, Germany in 2021 where following an explosion at the Currenta waste incineration plant seven employees died and 32 more were injured with economic damages exceeding 20 million Euros. Offsite impacts were also frequent across the cases studied with over 125 injuries reported and the neighbouring community being alerted to confine indoors and/or evacuate in at least 15 cases. As a case in point, in Apex, North Carolina, U.S., in 2006, more than 17,000 residents were evacuated for at least 36 hours following a fire at the "EQ" hazardous waste treatment facility and more than 100 residents were hospitalised shortly for respiratory disorders. The economic impact of similar events was generally significant although not all cases included economic impact data. Overall, 19 incidents recorded such data, that when calculated together, represent a collective loss of over 77 million euros.

3.3 Initiating events

As shown in Figure 4, the JRC study found in most cases (32 cases or 38%) that mixing of incompatible waste led to unforeseen reactions initiating the accident sequence. In these cases, operational and/or organisational failures caused an unforeseen reaction during mixing of waste. The undesired reaction may have resulted from a number of factors, such as misidentification of the hazardous properties of the waste, poor training on the process or how to respond when an unexpected reaction occurs, and possibly also a failure to perform an adequate risk assessment for the process at hand.

Figure 3. Initiating events of the accident sequence



Source: JRC analysis, 2024

Almost a third of the cases (27 cases or 32%) indicated the presence of contaminants or particular waste streams that should not be in the process (e.g., aerosols or batteries in a furnace). Operators were not aware of, or did not know to be concerned about, the contamination of the waste stream before processing or storing the waste.

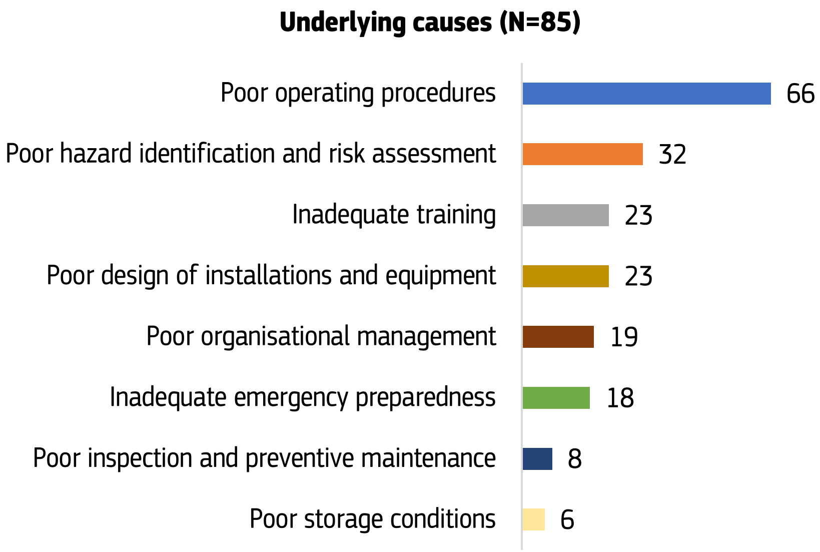
In nine cases (11%) a failure in the process equipment, such as the agitator, granulator, dryer, or scrubber led to loss of process control. In two of these cases, the sealings that ensure the safe hose hookup on vessels during the transfer of waste failed leading to loss of containment. Corrosion affecting the mechanical integrity of vessels and leading to the release of the hazardous waste content was also reported in two cases.

The omission of safe operating and storage requirements, such as temperature control, resulted in fires and/or explosions in six cases (7%). In three cases, ignition of flammable substances took place during hot work operations and in three others, batteries under storage or during processing, short-circuited and ignited.

3.4 Underlying causes and aggravating factors

As shown in Figure 5, the study revealed that poor operating procedures were the predominant underlying cause, contributing to 66 cases (77%). Additionally, the accident investigations showed that in many cases operators had failed to analyse properly the processes associated with the treatment and disposal of the hazardous waste streams. It appeared likely that in at least 32 cases (38%) process hazard analysis had failed to identify all hazards including, potential reactions or their full evolution.

Figure 4. Underlying causes



Source: JRC analysis, 2024

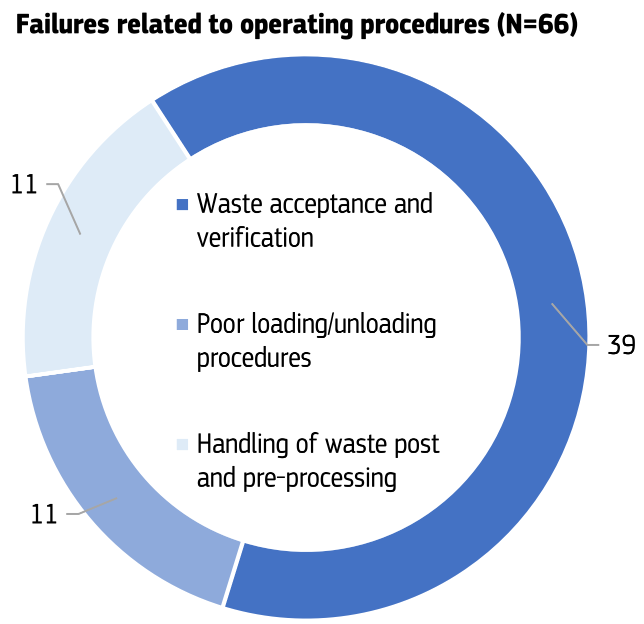
Notably, poor process hazard analysis was interconnected with deficiencies in other underlying causes since hazardous properties were either poorly identified or not identified at all. Poor or missing process hazard analysis (PHA) was also likely related to a number of other incidents, where the study identified:

- Lack of adequate training of employees (23 cases or 27%). In these cases, employees were not trained, or very poorly trained, on identification of hazardous properties and on how to respond during a process upset
- Poor process design, including equipment and installations, which was found to be inadequate for ensuring operation within the safe operating envelope in 23 cases (27%)
- Inadequate emergency preparedness, since accident scenarios selected for emergency drills were either not representative of the identified hazards or hazards were not identified at all during the PHA in at least 18 cases (21%)

3.4.1 Failures related to operating procedures

In almost half of the cases (39 cases or 46%), waste acceptance procedures, including analysis of the incoming waste, inspection and verification, were found to be inadequate or incomplete (see Figure 6). This finding was quite common in cases where operators accepted on-site hazardous waste that did not conform to the consignment documentation. In many cases, there were poor (or non-existent) pre-acceptance controls, such as inadequate or no visual inspection of consignments, or failure to sample and analyse the content of the waste, etc. prior to acceptance.

Figure 5. Failures related to operating procedures



Source: JRC analysis, 2024

Failure to screen waste at the entry point also led to poor sorting of the waste into different waste streams as required by the facility's operation permit, potentially leading to incompatibilities in waste storage and wrong choices in processing the waste. Moreover, in 11 cases (13%) poor operating procedures were related to loading/unloading operations referring mostly to missing or inadequate written procedures. Handling of waste and associated equipment before and after processing was also found inadequate in 11 cases (13%), where pre-treatment procedures were not followed or waste and associated process equipment was inappropriately handled after treatment, including, for example, poor cleaning of process vessels or poor temporary storage handling post-treatment.

3.4.2 Failures related to organisational management

Deficiencies were also identified in the overall organisational management of hazardous waste facilities for at least 20 cases (24%). More specifically, as per Figure 7, in at least 13 cases (15%) operators had experienced similar events in the past with milder or similar consequences without performing incident analysis and addressing the root causes. Similarly, operators had repeatedly received non-conforming waste in at least ten cases signalling poor management of waste suppliers and an inferior level of quality assurance. Communication among waste suppliers and treatment facilities on hazardous waste properties or optimal treatment process per waste received was reportedly found inadequate in five cases. Moreover, information on waste present on site, waste accompanying documentation and overall inventory management was found to be missing in at least four cases.

Figure 6. Failures related to organisational management

Source: JRC analysis, 2024

In some cases (eight or 9%), poor housekeeping or corrosion issues acted as underlying factors indicating poor inspection and preventive maintenance procedures while in six events, storage conditions were inappropriate exposing waste to substandard conditions (i.e., temperature/humidity/weather) or excessive waste quantities were held under storage.

The study also identified several aggravating factors for some of the cases studied. These factors magnified the consequences of the events without modifying their nature. In the absence of this factor, the event would still have taken place. These were mostly related to:

- Low level of activity, related mostly to workforce shortages (15 cases or 18%)
- Inadequate detection and monitoring systems to alert and mitigate loss of containment sooner (nine cases or 11%)
- Limited firefighting availability in six cases
- Presence of excessive waste quantities in three cases

3.5 Recommendations for checklist questions

This section provides a comprehensive checklist (see Box 2) tailored for operators and inspectors tasked with assessing the safety management practices of waste management facilities. The checklist encompasses key areas of concern stemming from the lessons learned analysis, including regulatory compliance, physical infrastructure, operational procedures, and emergency preparedness. By systematically addressing each item on the checklist, operators and inspectors can ensure thorough evaluations and contribute to the enhancement of safety standards within waste management facilities.

Box 2. Recommendations on checklist questions for operators and inspectors

- Are detailed chemical analyses, beyond consignment documentation, acquired for waste classification? Are experts involved in interpreting chemical analysis results for a comprehensive understanding of waste hazardous properties?
- Does the risk assessment take into account the overall risk profile, including hazards associated with loss of containment and mixture of incompatible substances? Is the risk assessment taking into account also releases that may occur during normal operation from the processing of waste?
- Is there a systematic process for incident analysis, documentation, and dissemination of findings to all levels of management? Does this process enable the adaptability of current handling practices and waste acceptance procedures based on the findings?
- Are there training programmes in place for new employees? Has the personnel associated with handling, loading/unloading operations received ADR training?
- Is infrared detection equipment and other appropriate detectors installed in areas where inflammable hazardous waste is handled or stored?
- Is there a strategic zoning of areas based on the classification of hazardous waste to reduce risks associated with incompatible materials?
- Is there a system in place to ensure timely sorting and processing of hazardous waste? Is this system accessible to the employees handling waste?
- Is there a thorough risk assessment considering low operational activity during breaks and holidays as well as during equipment downtime to avoid exceeding capabilities in handling and storing permitted waste quantities?
- Are procedures in place for controlling consignment documentation, filling in transfer checklists, and verifying incoming waste?
- Are there procedures in place for rejecting waste in case of discrepancies during pre-acceptance control? Is there a quarantine area appropriately monitored for the rejected consignments?
- Is there a quality management system in place? Is there an internal system for quality control? Do employees associated with waste pre-acceptance have access to report potential discrepancies to the quality management system?

4 Conclusions

The wide range of activities within waste management facilities results in a corresponding diversity of potential chemical accident scenarios. To effectively prevent and mitigate these risks, both technical and organizational measures tailored to each scenario must be implemented. By targeting operational practices, many accidents and incidents can be avoided. While recognizing recurring scenarios, it is imperative to conduct thorough risk analyses for each unique case, allocating resources accordingly to address potential operational failures, even those unforeseen. In the dynamic landscape of waste treatment, with continual increase in waste treatment requirements and particularly emerging risks, such as recycling of batteries from electrical vehicles, attention must be paid to the risks associated with newly developed activities and processes.

The findings from this lessons learned study can be used by operators and inspectors to enhance risk management in waste management facilities by identifying potential improvements in safety protocols, operational procedures, and emergency response strategies. By leveraging insights gained from the lessons learned study, operators and inspectors can proactively address vulnerabilities and implement preventive measures to mitigate risks effectively. This collaborative approach fosters a culture of continuous improvement, ultimately bolstering the overall safety performance and resilience of waste management facilities.

References

[1] "Council Directive 82/501/EEC of 24 June 1982 on the major-accident hazards of certain industrial activities," [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31982L0501. [Accessed 23 September 2023].

[2] "The Minerva Portal of the Major Accident Hazards Bureau," [Online]. Available: https://minerva.jrc.ec.europa.eu/en/minerva. [Accessed 3 September 2023].

[3] "Council Directive 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances," [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A31996L0082. [Accessed 12 September 2023].

[4] "Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC Text with EEA relevance," [Online]. Available: https://eur-lex.europa.eu/eli/dir/2012/18/oj. [Accessed 22 January 2024].

[5] BAPRI, "Overview of accident statistics on waste management facilities," October 2016. [Online]. Available: https://www.aria.developpement-durable.gouv.fr/wp-content/uploads/2017/06/2016-10-11-SY-AccidentologieDechetsVersionSimplifiee-PA-EN-Vfin.pdf. [Accessed 3 December 2023].

[6] Eurostat, "Waste statistics," 2023. [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics#Total_waste_generation. [Accessed 18 November 2023].

[7] "Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance)," [Online]. Available: https://eur-lex.europa.eu/eli/dir/2008/98/oj. [Accessed 11 September 2023].

[8] "2000/532/EC: Commission Decision of 3 May 2000 replacing Decision 94/3/EC establishing a list of wastes pursuant to Article 1(a) of Council Directive 75/442/EEC on waste and Council Decision 94/904/EC establishing a list of hazardous waste pursuant to Art," [Online]. Available: https://eur-lex.europa.eu/eli/dec/2000/532/oj. [Accessed 12 November 2023].

[9] “Commission notice on technical guidance on the classification of waste (2018/C 124/01),” [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018XC0409(01). [Accessed 5 November 2023].

[10] T. Talvitie and A. Isotalo, “Dangerous chemical reaction at a waste recycling plant in Järvenpää on 19 September 2022,” Turvallisuus- ja kemikaalivirasto (Tukes), [Online]. Available: https://tukes.fi/documents/5470659/6373020/Onnettomuustutkinnan+esittely_en.pdf/a5745a77-4638-db37-20a9-763c965bf3df/Onnettomuustutkinnan+esittely_en.pdf?t=1676635801174. [Accessed 16 November 2023].

[11] “Dangerous chemical reaction at a waste recycling plant,” eMARS, [Online]. Available: https://emars.jrc.ec.europa.eu/en/emars/accident/view/82f91fb9-14a3-11ee-988e-0050563f0167. [Accessed 6 October 2023].

[12] “Fire in a hazardous waste storage facility at a treatment centre,” BARPI, ARIA, [Online]. Available: https://www.aria.developpement-durable.gouv.fr/accident/48274_en/?lang=en. [Accessed 5 October 2023].

[13] “Poisoning in a wastewater treatment plant during dumping,” BARPI, ARIA, [Online]. Available: https://www.aria.developpement-durable.gouv.fr/accident/37516_en/?lang=en. [Accessed 4 February 2024].

[14] “Error while transferring acid at a household waste incineration plant,” BARPI, ARIA, [Online]. Available: https://www.aria.developpement-durable.gouv.fr/accident/43406_en/?lang=en. [Accessed 7 November 2023].

[15] “Incompatible mix at a hazardous waste treatment facility,” BARPI, ARIA, [Online]. Available: https://www.aria.developpement-durable.gouv.fr/accident/42944_en/?lang=en. [Accessed 3 December 2023].

[16] “Fire in a battery storage cell at a waste site,” BARPI, ARIA, [Online]. Available: https://www.aria.developpement-durable.gouv.fr/accident/43973_en/?lang=en. [Accessed 7 December 2023].

List of abbreviations and definitions

Abbreviations	Definitions
ADR	Agreement concerning the International Carriage of Dangerous Goods by Road
ARIA	Analysis, Research and Information on Accidents
BARPI	French Bureau for Industrial Risks
BPCS	Basic Process Control System
CAPP	Chemical Accident Prevention and Preparedness
CLP	Classification, Labelling and Packing (CLP) Directive
CSB	Chemical Safety Board
EC	European Commission
eMARS	electronic Major Accident Report System
EoL	End of Life
EU	European Union
HHW	Hazardous Household Waste
IEC	International Electrotechnical Commission
IR	Infrared
ISA	International Society of Automation
JFKD	Japan Failure Knowledge Database
JRC	Joint Research Centre
LLB	Lessons Learned Bulletin
MAHB	Major Accident Hazards Bureau

Abbreviations	Definitions
NCR	Non-Conformity Report
PHA	Process Hazard Analysis
QA	Quality Assurance
QR	Quick Response code
SHW	Special Household Waste
SIF	Safety Instrumented Function
SIS	Safety Instrumented System
SMS	Safety Management System
TUKES	Turvallisuus- ja kemikaalivirasto
UN	United Nations
UV	Ultraviolet
WFD	Waste Framework Directive
ZEMA	Zentrale Melde- und Auswertestelle für Störfälle und Störungen in verfahrenstechnischen Anlagen

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