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Maritime Safety in Waste Management: Analyzing Risk of Occupational Accidents during Waste Incineration on Vessels

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Abstract: The advent of marine transportation poses several challenges, particularly concerning the disposal of waste generated by ships. Incineration of waste has proven to be an effective solution, significantly reducing on-board waste and facilitating its disposal at designated facilities upon arrival at the destination port. While waste can also be incinerated at sea in accordance with relevant regulations, this practice carries significant risks that can lead to workplace accidents. Therefore, this study aimed to identify potential risk factors for workplace accidents during waste incineration activities on ships using Failure Mode and Effects Analysis (FMEA). The risk levels of occupational accident were also assessed and analyzed to minimize workplace accidents. The FMEA analysis showed that the highest risk of workplace accidents was associated with hand injuries, with a Risk Priority Number (RPN) of 211.58 or 21.1% in the activity of burning waste in the ship´s incinerator.

Keywords: Occupational Accidents Risk Mitigation, shipboard trash burning, incinerator, FMEA

1. Introduction

Proper management and control of ship-generated waste are crucial to prevent marine pollution. The International Convention for the Prevention of Pollution from Ship (MARPOL 73/78) has established certain regulations to manage and control pollution from ships, including the disposal of waste. However, challenges in implementing these regulations persist in some countries, leading to instances of non-compliance [1]. The lack of environmental protection equipment on ships contributes to marine pollution, including the discharge of untreated sewage [2]. Waste generated by ships is considered a source of pollutants, with plastics and microplastics posing a significant threat to the marine environment and human health [3]. Although waste handling on ship is regulated, previous studies indicate that illegal disposal into the sea still occurs, negatively affecting the marine environment and human safety [4]. Ship demolition is another major source of marine pollution due to the improper recycling of toxic chemicals [5].

Effective management is essential in addressing the challenges of marine waste, which poses challenges for various stakeholders, including the shipping industry. The International Convention for the Prevention of Pollution from Ship (MARPOL) has established a significant agreement aimed at reducing ship-sourced marine pollution [6]. However, the implementation of international agreements and policies alone is insufficient to resolve the waste problem, as it requires stronger enforcement [7]. In Peru, the lack of facilities for receiving and disposing of waste from small-scale fishing fleets poses significant risks, including hazardous waste such as batteries [8]. Offshore drilling operations require waste removal to ensure the stability and safety of subsea structures [9]. Marine waste can also negatively impact fishing activities, resulting in a decline in production and income for fishermen [10]. Therefore, effective ship waste management is recommended to mitigate the environmental and economic impacts.

In the future, it is anticipated that the problem of waste originating from passenger/cruise ships will increase, given the current demand for cruise ships. Approximately 25 percent of all waste generated by all types of ships comes from cruise ships [11]. A ship with 3000 passengers produces approximately 21 tons of solid waste during a one-week cruise, because each passenger generates approximately 1 kg of waste per day [12]. The choice of waste management methods such as waste collection and disposal depends on the type and size of the ship and the equipment available on board [13]. The waste management flow on passenger ships is shown in Figure 1 below:

Fig. 1 (A). Garbage on the deck of the ship, (B) Garbage is collected and sorted (C) Inorganic waste bin on the ship, (D) Organic waste bin on the ship, (E) Garbage is collected in plastic bags, (F) Incinerator, (G) Garbage is put in a truck (H), waste is transported to port reception facilities.

Source: authors

Waste management on ship encompasses a range of methods, including collection, separation, processing, storage, and disposal at sea, as outlined by regulations. However, studies suggest that ships frequently use various treatment methods addressing only a portion of the waste stream. This results in a disparity between the amount of waste generated and the amount properly managed, highlighting the need for more sustainable and operationally effective waste management practices on ships. While the International Maritime Organization (IMO) has implemented Waste Management Plans, voluntary cooperation between ports and the shipping sector is encouraged to address this disparity [14]. The role of the master and crew is also crucial in maintaining onboard cleanliness and adhering to MARPOL regulations, while port health authorities provide waste disposal facilities and oversee sanitation on ships [15]. Innovative solutions, such as energy recovery from solid waste through absorption plants facilitate the reduction of environmental impact and fuel consumption on cruise ships [16]. Furthermore, the decision-making process for ship recycling should consider the environmental effects of dismantling compared to storage to determine the most appropriate method and location [17]. The increasing volume of marine waste, particularly plastics, poses significant challenges, leading to the establishment of international and EU regulations aimed at managing ship waste and reducing the recycling impacts on the environment [13].

Waste treatment on ships involves various methods, with incineration being a common method. Incineration can reduce the need for storage space and facilitate disposal at waste facilities upon arriving at port [18]. However, incineration has several notable limitations, posing harmful environmental and health risks [19]. Open burning of waste, particularly plastics, releases harmful chemicals and particles that threaten public health and the environment [20]. Furthermore, open burning of municipal solid waste (MSW) in developing countries releases pollutants such as fine particulate matter (PM2.5) and black carbon (BC), which negatively impact air quality in urban areas [21]. These emissions pose a substantial risk to waste pickers, who often work without adequate protective equipment or a safe working environment [22]. Waste fires, including those caused by open burning, have detrimental effects on the environment, public health, and the economy [23]. Therefore, there is a need to promote sustainable waste management practices and enforce more stringent fire safety regulations to mitigate the harmful effects of burning waste [24].

Before disposal, waste sorting is crucial and should be based on the tools and equipment used for processing. A shipboard waste incinerator is a specialized system with various components, including a fuel chamber, combustion furnace, air blower, temperature indicator, ash handling system, and water scrubber. However, the use of incinerator has negative consequences, such as harmful exhaust emissions that can adversely affect both human health and the environment [25].

According to Annex VI of the Marine Pollution Convention of 1973/1978, specific materials are prohibited from being incinerated. These include waste containing iron scraps, refined oil products with halogenated materials, polychlorinated Biphenyls (PCBs), and cargo residues such as oil, noxious liquids, and harmful substances [26]. The combustion of these materials can lead to air pollution, with detrimental effects on both human health and the environment [27]. Waste incineration can also pose risks of emissions and accidents [28] including hazards such as bumping, hitting, trapping, falling, heavy workloads, electricity-related incidents, and burning [29]. A previous study has shown that the safety behaviour of crew members can affect waste handling on board [4]. This is because the human factor and technical errors can lead to ship fires or explosions, resulting in loss of life, property damage, and environmental harm [30]. Consequently, conducting risk analyses is essential to mitigate the impacts of waste disposal activities.

Based on existing studies, burning waste poses significant risks to safety, health, and the environment [23,25,26]. However, previous study has not thoroughly identified the various types of occupational accidents risks associated with handling waste on ships equipped with incinerators, nor has it addressed the specific factors and priority areas needed to minimize the risk of occupational accidents. Therefore, this study aims to identify workplace accidents related to burning waste on ships, considering potential risk factors. Further analysis was also carried out to assess risk levels associated with workplace accidents arising from waste incineration. The novelty of this research is in its focus on prioritizing the main causes of workplace accidents during waste burning on ships. The findings are expected to contribute to the reduction of workplace accidents.

2. Data and Methods

This research employs quantitative methods utilizing FMEA (Failure Mode and Effects Analysis). A sample of 60 passenger ship crew members from 3 Indonesian-flagged passenger ships, all operating from and arriving at the port of Tanjung Perak, Indonesia, was analyzed. The sample size was determined at 5 to 10 research factors [31]. In this study, 12 factors related to the risk of accidents during waste incineration were identified, leading to the calculation of the sample size as 5 multiplied by 12 (accident risk factors), resulting in a total of 60 participants.

The factors associated with workplace accidents and their risks during waste incineration are categorized as follows: Burns (1) Hands exposed to hot liquid incinerator fuel (2); Hands Exposed to fuel heater; Wounds (3) Pinched fingers; (4) Injured hands; Slips (5) Bruised leg, (6) Head hit, (7) Fracture; Eye disorders (8) Bruised leg (9) Dust in eyes; Respiratory disorders (10) Inhaling gas (11) Inhaling dust; Electrocution (12) Electric shock during the waste-burning process.

The data collected were used to assess the risk of workplace accidents employing the FMEA method. After obtaining the Severity (S), occurrence (O), and Detection (D) values, Risk Priority

Number (RPN) and the percentage occurrence of each type of workplace accidents associated with waste incineration were calculated using the formula presented below:

$$RPN = S \cdot O \cdot D, \quad [-] \tag{1}$$

where [32]: Severity (S) defines the strength of failure impact on the system and is associated with the consequences of the failure modes. It is rated on a scale of 1-10; Occurrence (O) is the probability that a failure mode will occur; it is closely related to the failure rate of the equipment. It is rated on a scale of 1-10; Detection (D) indicates the likelihood of detecting the failure mode before its effects manifest in the system. The effectiveness of current preventive measures is evaluated on a scale of 1-10.

$$\text{Percentage of Risk Events} = \frac{RPN}{Total\ RPN} \cdot 100, \quad [\%] \tag{2}$$

where: RPN is RPN risk event [-]; Total RPN is total RPN overall [-].

Risk ratings were categorized as follows: very low (x < 20), low (20 ≤ x < 80), medium (80 ≤ x < 120), high (120 ≤ x < 200), and very high (x > 200). This categorization allows for determining the highest level of preventive and mitigating actions to ensure the smooth continuation of activities [33]. The highest accident rate in waste incineration on merchant ships using incinerator represents the most critical risk, demanding priority action to minimize the occurrence of workplace accidents during waste incineration on ship. The research flow diagram is shown in Figure 2 below:

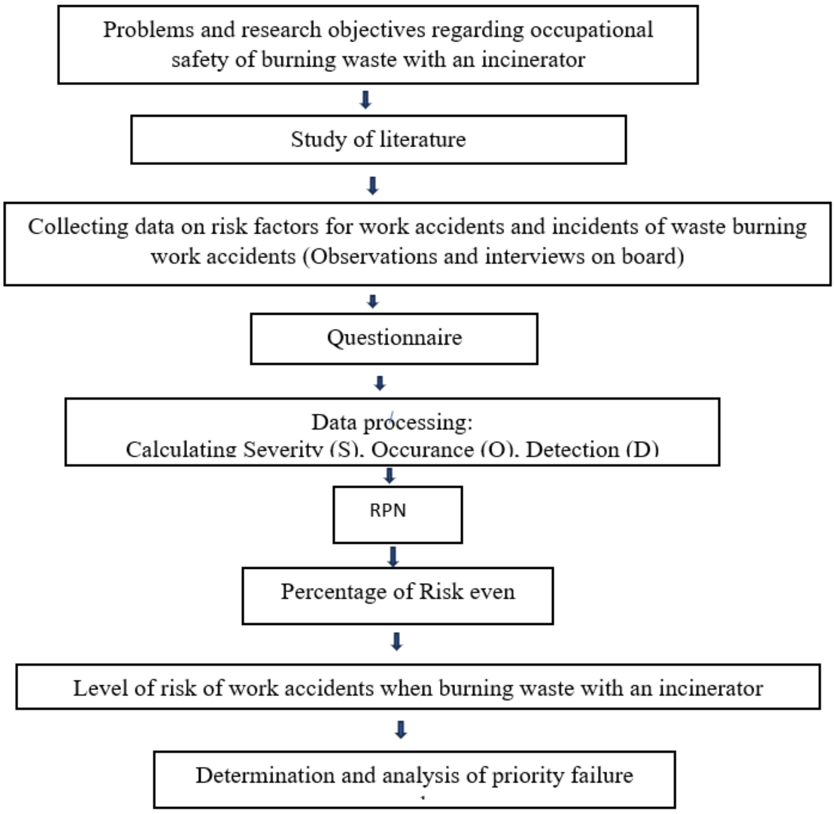

Fig. 2 Research flow diagram analyzing risk of occupational accidents during waste incineration on vessels. Source: authors

3. Results

A total of 60 crew members were assessed based on the Severity (S), Occurrence (O), and Detection (D) aspects of the 12 work safety incident, including the burning of waste using an incinerator on passenger ships departing from and arriving at the Port of Tanjung Perak Indonesia. Risk assessment was conducted to determine the level of risk for workplace accidents using RPN method. The results of the Severity, Occurrence, and Detection assessments are shown in Figure 3.

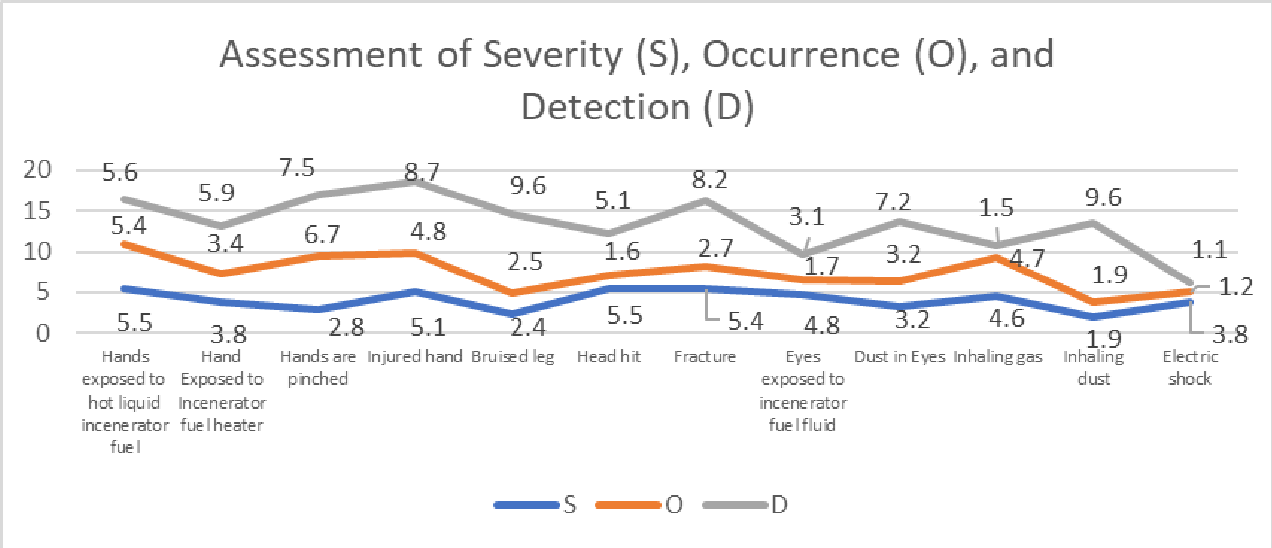

Fig. 3 Evaluation of S, O, D, and Risk of Accident Occurrence during Waste Incineration.

Source: authors

The figure illustrates the risk factor and types of accidents associated with waste incineration on passenger ships departing from and arriving at the Port of Tanjung Perak Indonesia. For each accidents risk, the Severity (S), Occurrence (O), and Detection (D) assessment values are shown, representing the average assessment values for the 60 crew members on passenger ships departing from and arriving at the Port of Tanjung Perak Indonesia. Subsequently, the RPN is calculated by multiplying the S, O, and D for each accidents risk. The results highlight the differences in RPN values for each accidents risk during waste incineration with an incinerator. The RPN values are ranked in descending order to determine the top priorities requiring immediate remedial action. The ranking of RPN values for accidents risk, from the highest to the lowest, is presented in Figure 4.

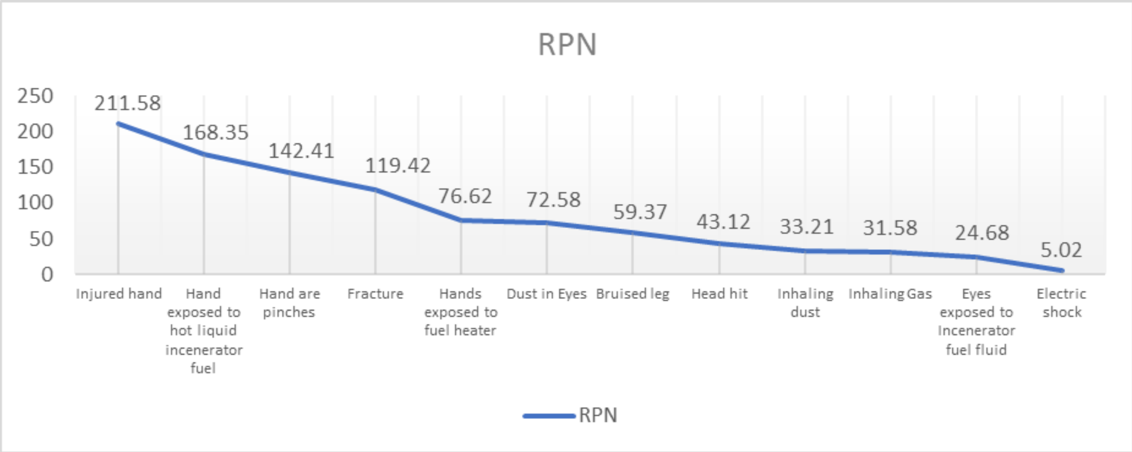

Fig. 4 RPN values for occupational accidents in waste incineration. Source: authors

As seen in Figure 4, the risk factor values for workplace accidents during waste incineration are displayed, ranging from the highest to the lowest values of RPN. Additionally, the highest RPN value is 211.58 occurring in hand injury risk events, indicating a fairly high-risk level. This is due to the transportation of waste from the deck to the engine room, as well as the transportation of ash from the engine room to the deck. Hand injuries also occur frequently during the process of heating fuel and burning waste using incinerators. The percentage of each risk event is calculated by dividing the RPN for that event b the total RPN, then multiplying by 100%. In this study, the total RPN in this study was 987.9. The percentage distribution of risk events is shown in Figure 5.

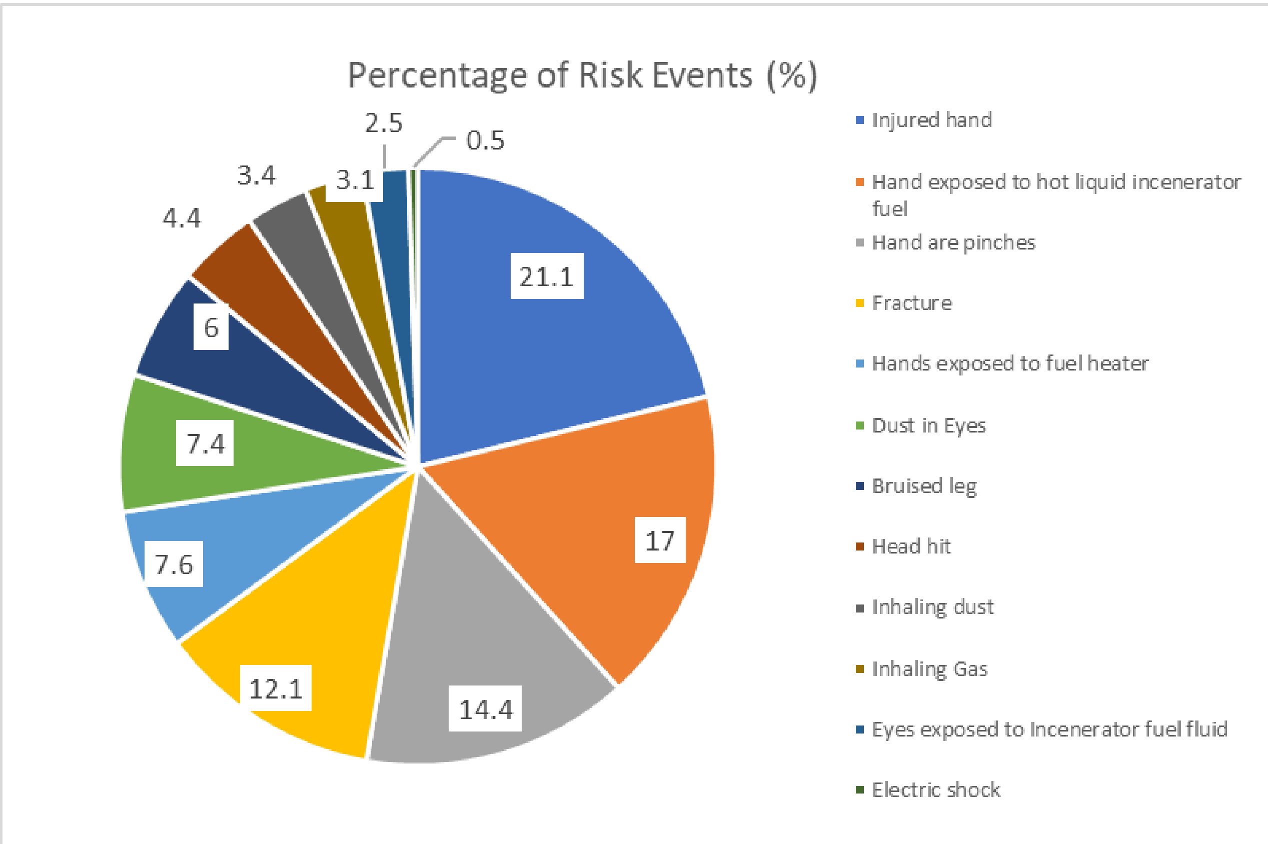

Fig. 5 Percentage of risk event for occupational accidents in waste incineration. Source: authors

4. Discussion

Based on the FMEA method, several stages are involved in the waste incineration process in the engine room of passenger ships. This includes transporting waste from the ship´s disposal facility on the deck to the incinerator located in the engine room, as well as carrying ash from the incinerator back to the deck. Additional activities include carrying ash from incinerator to the deck, heating fuel, and incinerating waste. During this process, 12 types of accidents were identified, each corresponding to 6 distinct workplace accidents risk factors.

Risk associated with workplace accidents at incinerator facilities included burns, cuts, eye irritation, respiratory issues, and electric shock. The risk of burns was identified when hands were exposed to hot fuel incinerator and during heating. The risk of cuts arose in the event of hand entrapment during incinerator cleaning and maintenance, as well as during the disposal of waste and removal of ash. Slips and falls were potential hazards occurring during the transport of waste from the deck to the incinerator located in the engine room or while carrying ash. Risk of eye irritation is associated with exposure to incinerator fuel and burning waste, while respiratory issues were linked to the inhalation of gases and ash during waste disposal. The risk of electric shock was recognized during electrical incidents, including those related to the installation of the incinerator system.

The occurrence of workplace accidents during waste incineration on passenger ships was identified through observations and interviews with the chief engineer. The results showed that, although the shipping company provided safety equipment for personal protection, crew members were not consistently disciplined in using it. The implementation of waste incineration was not in accordance with the procedure and the working environment was also identified as a contributing factor to accidents. This aligns with the study by [4], which suggests that crew safety behavior influenced waste management on board ships. [30] also stated that human factors can be a potential cause of losses in terms of life, property, and the environment. Environmental factors, such as the location of the incinerator in the engine room on the lower part of the ship, further exacerbated the risks, particularly when negotiating step and slippery stairs during the transportation of waste and ash.

These findings are consistent with previous research that burning waste has an impact on human health and the environment [27]. Waste burning has also been linked to various accidents [28], including bumping, hitting, trapping, falling, heavy workloads, electricity-related incidents, and burning [29]. The novelty of this research lies in its ability to calculate the RPN value and percentage of risk events, allowing for the prioritization of actions to reduce the risk. Injury prevention in the workplace is crucial, and identifying and managing potential hazards is essential. Based on RPN assessment, hand injuries presented the highest risk during waste incineration on ships. These injuries commonly occurred during the transport of waste to the engine room, where sharp objects posed a threat, as well as during the cleaning of ash and the fan that pumps oxygen into the incinerator. Given the high RPN associated with hand injuries, prioritizing preventive measures is essential. Efforts to minimize accidents during waste incineration on ships can be made by enhancing crew understanding and discipline regarding the proper use of protective equipment, such as safety shoes, helmets, high-protection gloves, safety goggles, and masks. Emphasizing hand protection by using high-protection gloves and ensuring that burning waste is carried out according to the established procedure is crucial.

5. Conclusion

This study shows that the use of incinerators for waste disposal on passenger ships poses 12 workplace accidents, categorized into 6 risk factors, including burns, cuts, slips, eye irritation, respiratory problems, and electric shock. These workplace accidents associated with waste incineration on board ship were ranked by risk level from highest to lowest, including hand injury, hand exposure to hot incinerator materials, hand crushing, bone fracture, hand exposed to heating incinerator materials, eye irritation, leg burns, head injury, inhalation of dust and gas, and electric shock. The novelty of this research is that it can determine the RPN value of the risk of waste-burning accidents in incinerators. According to the RPN assessment using FMEA, hand injury had the highest RPN value of 211.58 (21.1%) with a very high-risk level.

Prioritizing preventive efforts based on the RPN score and risk level is crucial to minimizing workplace accidents during waste incineration on board ship. Efforts to address the highest risk associated with waste incineration on ship for crew members should focus on the comprehensive use of personal protective equipment. This includes high-protection gloves to prevent injury during waste insertion into incinerator, removal of ash from incineration process, and maintenance of the incinerator. Crew members should receive training to increase awareness and adherence to safety equipment provided by the shipping company, as well as to improve their understanding of waste incineration procedures. Additionally, it is recommended that shipping company management conduct regular monitoring and evaluation to ensure compliance with waste incineration procedures and minimize the risk of workplace accidents. Future research should explore the relationship between factors influencing crew awareness and discipline in adhering to safety procedures while maintaining protective equipment.

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