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Demilitarization Risk Management Of Ammunition And Explosives At Storage Depots Using The Sloping Method Through The Application Of HIRADC

1st Nunik Endah Sulistiyawati
Interdisciplinary School of Manajement Technology Institut Teknologi Sepuluh Nopember
Surabaya
nuniekendahsulistiyawati2229@gmail.com

2nd Bambang Syairudin
Departement of Industrial and Systems Engineering
Institut Teknologi Sepuluh Nopember
Surabaya
bambang.syairudin@its.ac.id

3rd Buana Ma'ruf
Research Center for Hydrodynamic Technology
The National Research and Innovation Agency (BRIN)
Surabaya
buana.maruf@brin.go.id

Abstract*—Management of expired and damaged ammunition and explosives in storage depots is a significant challenge because it has a high risk of explosion and radiation that threatens the health and safety of personnel, material and the environment. This study aims to formulate a risk mitigation strategy by applying the sloping method in the demilitarization process combined with the HIRADC (Hazard Identification, Risk Assessment, and Determining Control) approach. The application of this combination is to identify, assess, and control risks that may arise during the demilitarization process. HIRADC provides a systematic framework for understanding various risks and determining effective preventive measures, while the sloping method helps in the safe management of materials. This study shows that the combination can improve efficiency and reduce potential accidents and environmental impacts. This study significantly contributes to developing a safer and more sustainable risk management model and a more comprehensive risk mitigation policy to improve personnel safety, protect the environment, and optimize the long-term management of ammunition and explosives.

Keywords— Risk Management, Demilitarization, Ammunition and Explosives, HIRADC.

I. Introduction

The demilitarization of ammunition and explosives is critical to security and safety within the defense industry (1). This process is essential for managing ammunition that has reached its usage limit or has been damaged (2), aiming to prevent potential explosions and environmental contamination risks (3). Improper handling can negatively impact personnel, strategic assets, and ecosystems. Therefore, the development of a comprehensive and systematic risk management strategy is essential to ensure that the demilitarization process is conducted safely and efficiently (4).

The sloping method used in the demilitarization of ammunition provides a specialized approach to addressing the risks arising from the storage and destruction of explosives (5). One effective method for assessing and mitigating these risks is through the application of Hazard Identification, Risk Assessment, and Determining Control (HIRADC) (6). The implementation of HIRADC is used to identify potential hazards in detail, conduct deeper risk analysis, and apply more appropriate control measures to reduce potential adverse impacts during the demilitarization process (7).

In a complex operational environment, the application of HIRADC not only helps in identifying potential hazards but also guides in selecting the most effective control methods (8), including the use of the sloping method, which has been proven to reduce the potential for explosions during the demilitarization process (9). This is done according to classifications based on the characteristics and effectiveness of the ammunition and explosives (10). This paper focuses on applying HIRADC in risk management to enhance operational safety, reduce accident risks, and minimize environmental impacts in the demilitarization of ammunition and explosives (11).

II. CONTEXTS OF DEMILITARIZATION

A. Demilitarization

The demilitarization and disposal process of ammunition principally involves the disassembly of ammunition, allowing various materials and explosives to be separated (12). If any materials are found to have significant value for reuse, they will be utilized according to their needs and benefits (13). Meanwhile, hazardous materials that require further processing or disposal as waste will undergo a process that is safe, economical, and environmentally responsible (14). The demilitarization stages are carried out based on the technical classification of the types of ammunition and explosives (15). This is done as an effort to minimize the risk of explosions, radiation, and other hazardous effects that threaten the safety of personnel, materials, and the surrounding environment (16).

B. *Factors Influencing Demilitarization*

The demilitarization of ammunition and explosives is a critical process in the life cycle of weaponry (17), particularly in the context of managing stockpiles that have exceeded their service life (18). This process involves the destruction or recycling of ammunition and explosives that are no longer fit for use due to factors such as age, damage, or changes in operational needs (19). One of the main factors driving the importance of demilitarization is the safety risk posed by expired or damaged ammunition (20). Improperly handled ammunition can lead to fatal accidents for personnel, infrastructure damage, and significant environmental impacts (21).

Additionally environmental concerns have become a key focus in the demilitarization process (21). Increasingly stringent international and national regulations regarding the management of explosive waste compel military authorities to develop more environmentally friendly methods for ammunition disposal or recycling (22). Factors such as air pollution, soil contamination, and water contamination from chemical residues require special attention during the demilitarization process (23).

As a result, technology-driven approaches, such as the application of the inclined method through HIRADC (Hazard Identification, Risk Assessment, and Determining Control), have become crucial in enhancing operational safety and reducing risks to personnel and the environment (24).

Another factor influencing demilitarization is the high costs involved in the process (25). This includes the logistics costs, the technologies used, and the training of personnel to handle complex and high-risk processes (26). Inefficient demilitarization can result in resource waste and increase risks to public health and safety (27).

Therefore, optimizing risk management with a multi-criteria approach is necessary to ensure that the demilitarization process is safe, efficient, and environmentally friendly (28).

III. RESEARCH METHODOLOGY

A. *The Demilitarization Planning Process*

Before conducting the demilitarization process, it is essential to develop a plan that ensures the sustainability of the activity and minimizes harmful risks (29). The first step involves identifying expired or damaged materials and determining their hazardous nature. Then, the potential dangers related to handling, storage, and transportation, such as explosion risks, chemical reactivity, and toxicity, are assessed (30).

Next, the environmental impact and regulatory requirements must be reviewed to ensure compliance with waste management and disposal standards (31). This step forms the basis for determining the appropriate demilitarization methods and the resources required. Various methods can be applied to demilitarize ammunition and explosives, based on their type, condition, and composition (32). The demilitarization planning process can be outlined in Fig 1.

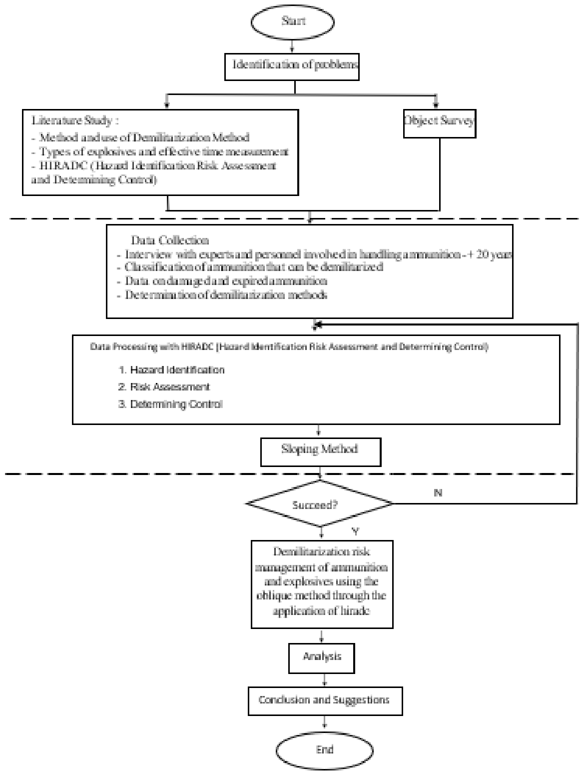

Fig 1. Flowchart for demilitarization of ammunition and explosives through the application of hiradc

B. *Demilitarization process with the application of HIRADC*

Fig 1 represents the initial design steps undertaken in the research method through a flowchart of ammunition and explosives demilitarization, applying the HIRADC approach. It begins with the identification of problems occurring in the ammunition and explosives storage depots. The identification phase serves as the initial step, aimed at classifying the characteristics of the ammunition to be utilized. A literature review and object survey are conducted to assess whether the material is suitable and feasible for reuse.

Data collection and the application of HIRADC are carried out to develop a technical system design concept for the explosive disposal process, known as sloping. This is done with the expectation that the ammunition can be utilized while minimizing the risk of workplace accidents. The analysis of the results in the demilitarization process is performed to provide considerations for decision-making regarding the sustainability of reuse feasibility.

IV. RESULT

A. *Technical System Analysis*

The technical system analysis is conducted during the demilitarization process to implement the concept of ammunition utilization, such as coordinating support personnel in tasks like classifying types of ammunition, transportation, creating utilization devices, ammunition assembly and disassembly processes, fixed and variable cost calculations, supporting equipment, and obtaining permits to support these activities.

The sloping method is a demilitarization implementation activity that involves tilting. This is done because during the process of removing explosives from the ammunition, it is tilted at a 30º angle, making it easier to empty the ammunition. The sloping activity can be seen in Fig 2.

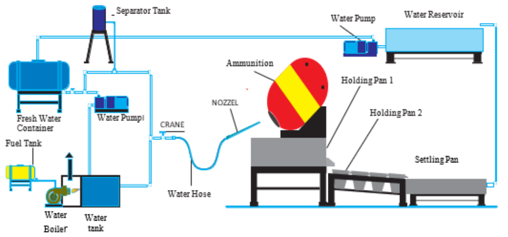

Fig 2. Sloping process

The sloping process activity in Figure 2 can be explained by the concept of creating supporting tools and personnel, which involves both fixed costs and variable costs, as shown in Table 1 and Table 2.

TABLE I. FIX COST

No	Item Fix Cost	Qty	Unit	Price	Total
1.	Water Tank	1	Unit	Rp. 28.000.000	Rp. 28.000.000
2.	Special Tools	1	Set	Rp. 12.000.000	Rp. 12.000.000
3.	Special Mask	15	Pcs	Rp. 280.000	Rp. 4. 200.000
4.	Gloves	15	Set	Rp. 150.000	Rp. 2.500.000
5.	Project Helmet	15	Unit	Rp. 50.000	Rp. 750.000
6.	PPE	10	Pcs	Rp. 200.000	Rp. 2.000.000
7.	Burner	1	Unit	Rp.128.000.010	Rp.128.000.000
8.	Glasses	15	Pcs	Rp. 100.000	Rp. 1.500.000
9.	Fuel Tank	1	Unit	Rp. 32.000.000	Rp. 32.000.000
10.	Circulation Pump	1	Unit	Rp. 8.000.000	Rp. 8.000.000
11.	Dough Mixer Machine	1	Unit	Rp. 12.000.000	Rp. 12.000.000
12.	Reservoir Tank	2	Pcs	Rp. 150.000	Rp. 300.000
13.	Reservoir Pan	4	Pcs	Rp. 150.000	Rp. 600.000
14.	Sedimentation Tank	2	Pcs	Rp. 150.000	Rp. 300.000
15.	Granding Machine	1	Unit	Rp. 38.000.000	Rp. 38.000.000
16.	Special Hose	20	Meter	Rp. 100.000	Rp. 2.000.000
17.	Connecting Pipe	10	Stick	Rp. 80.000	Rp. 800.000
18.	Nozzle	1	Pcs	Rp. 470.000	Rp. 470.000
19.	Faucet	2	Pcs	Rp. 90.000	Rp. 180.000
20.	Supporting Equipment	-	-	Rp. 8.900.000	Rp. 8.900.000
					Rp. 318.000

TABLE II. VARIABEL COST

No	Item Variabel Cost	Qty	Unit	Price	Total
1.	Solar Deck	105	Liter	Rp. 11.350	Rp. 1.191.750
2.	Oil	3	Liter	Rp. 65.000	Rp. 195.000
3.	Electricity	-	-	Rp. 1.450.000	Rp. 1.450.000
4.	Sterile Milk	10	Kaleng	Rp. 10.000	Rp. 100.000
5.	Green Beans	-	-	Rp. 60.000	Rp. 60.000
6.	Mineral Water	2	Galon	Rp. 15.000	Rp. 30.000
7.	Vitamins	2	Pak	Rp. 30.000	Rp. 60.000
8.	Honey	2	Botol	Rp. 150.000	Rp. 300.000
9.	Extra Pudding	-	-	Rp. 350.000	Rp. 500.000
					Rp. 2.910.000

B. Fix and Variable Cost

Fixed costs are fixed expenses incurred for assembling the equipment needed for sloping activities. These costs are incurred only once unless there is a change in the sloping activity. On the other hand variable costs are incurred each time the sloping activity is performed. Demilitarization using the sloping method aims to utilize the explosives in ammunition according to their function but in different conditions. The development of this method is expected to result in a more effective, efficient, and beneficial outcome. The application of HIRADC in the sloping process is as follows:

* Hazard identification: Activities must be aware of the conditions and circumstances that could lead to workplace accidents and side effects, such as diseases caused by ammunition radiation. Control and prevention measures are implemented as preventive steps in demilitarization activities.
* Risk assessment: Evaluating the severity of risks that occur by calculating the likelihood of incidents to map the hazard levels, ranging from the lowest to the most severe or average in the activity.
* Determining control: This refers to controlling hazards and risks in the demilitarization process in accordance with SOPs, considering the hierarchy of control measures such as elimination, substitution, isolation, engineering control, administrative control through signs or warnings, and personal protective equipment (PPE). These rules must be followed and adhered to as efforts to minimize workplace accident risks in the working environment.

V. DISCUSSION

The calculation of material capacity values for supporting demilitarization activities and the results of the risk identification were obtained by applying HIRADC. Risk Management in Ammunition and Explosives Demilitarization at Storage Depots through the Sloping Method using HIRADC can be assessed and controlled through the following calculations and analyses:

A. In sloping activities, the value derived from calculations represents the capacity of the material to support sloping activities, such as:

* A freshwater tank used for extracting the explosive content slated for sloping. The tank specifications are: 1.5 meters in length, 80 cm in width, with a diameter of 0.8 meters and a height of 100 meters. Calculation details are as follows:

$$½ X d X t = \pi r^2 X (½) X t = 22/7 X (0,4)^2 X ½ X 1 = 3,14 X 0,16 X 0,5 X 1 = 0,251 m^3 = 0,251 X 10^3$$

so it can hold water with a water volume of 251 dm^3

* The separator tank is used to reduce steam pressure within the pipe, as the heat generated by the water boiler increases; with rising heat, the pressure also increases. This measure is to prevent excessive pressure on the installed pipes, which could lead to pipe rupture. The tank specifications are: 1 meter in length, 60 cm in width, with a diameter of 0.6 meters and a height of 100 meters. The calculation details are as follows:

$$½ X d X t = \pi r^2 X (½) X t = 22/7 X (0,3)^2 X ½ X 1 = 3,14 X 0,9 X 0,5 X 1 = 1,413 m^3 = 1,413 X 10^3$$

so that the steam capacity in the tank is able to accommodate a water volume of 141 dm3.

* The fuel tank is used to supply fuel supporting the operation of the water boiler in the sloping process. The tank specifications are: 1 meter in length, 100 meters in width, with a diameter of 100 meters and a height of 100 meters. The calculation details are as follows:

$$½ X d X t = \pi r^2 X (½) X t = 22/7 X (0,5)^2 X ½ X 1 = 3,14 X 0,25 X 0,5 X 1 = 0,3925 m^3 = 0,3925 X 10^3$$

so it can accommodate fuel in the form of diesel with a volume of 392.5 liters.

* The water tank is used to hold hot water heated by the water boiler, which is then sprayed to expel the explosive contents in the sloping process. The tank specifications are: 1 meter in length, 100 meters in width, with a diameter of 100 meters and a height of 100 meters. The calculation details are as follows:

$$½ X d X t = \pi r^2 X (½) X t = 22/7 X (0,5)^2 X ½ X 1 = 3,14 X 0,25 X 0,5 X 1 = 0,3925 m^3 = 0,3925 X 10^3$$

* Circulation pump with a pressure of 150 Bar, which functions to circulate water from the freshwater tank to the water boiler and is subsequently stored in the water tank.
* Pipes with dimensions of 2.5 Ø, 4 sections (6 meters per section), and 2 Ø, 3 sections (6 meters per section) serve as conduits for water in the sloping process.
* Valve 2 Ø to open and close the water flow when the sloping process begins.
* Heat Pipe water hose 5 meters in length, serves as the conduit for hot water to be sprayed onto the explosives in the sloping process.
* Nozzle 0.3 Ø as a spraying tool in the sloping process.
* Water catchment basin functions to collect residual water from the sloping process, with dimensions of 1 meter in length, 1 meter in width, and 1.5 meters in height. The calculation details are as follows:

$$\text{Length X Width X Height} = 100 X 100 X 150 = 1{,}500{,}000 m3 = 1500 dm^3.$$

* The sedimentation basin is used to collect residues from the explosives after the sloping process. The specifications are: 1 meter in length, 100 meters in width, and 100 meters in height, with calculations as follows:

$$\text{Length} \times \text{Width} \times \text{Height} = 100 \times 100 \times 100 = 1{,}000{,}000 m^3 = 1{,}000 dm^3.$$

* The water pump is used to suction residual water from the collection pan with a pressure of 150 Bar.
* The water boiler functions as a water heater to melt the explosives at a temperature of up to 900°C during the sloping process, with a pressure of 15 psi.

B. Through the analysis of the application of HIRADC

* Identification of Ammunition Storage Warehouse Hazards and Control of Ammunition Storage Warehouse Risks can be classified through table 3.

TABLE III. IDENTIFICATION OF AMMUNITION STORAGE WAREHOUSE HAZARDS AND CONTROL OF AMMUNITION STORAGE WAREHOUSE RISKS.

No	Demilitarization Activity Identification	Location	Location	Hazard Identification	Risk	Hierarchy of Control.
1.	Temperature and humidity verification	Storage warehouse	Storage warehouse	High temperature and humidity	A chemical reaction occurs the risk	Using IoT-based temperature and humidity sensors connected to alarms, air circulation conditioning in storage warehouses, HVAC (Heating, Ventilation, and Air Conditioning) systems, updated temperature and humidity recording, use of PPE
2.	Ammunition material transportation process	Storage warehouse	Storage warehouse	Impact and friction	Explosion, disability, or death of personnel.	Implementing technical controls or modifications to transport equipment to reduce risks, training personnel involved in ammunition handling and transport procedures on safety procedures, and using personal protective equipment to protect personnel from potential hazards.
3.	Personnel not wearing PPE at certain times.	Storage warehouse	Storage warehouse	Workers trapped and crushed by ammunition.	Injuries, disabilities, and loss of bodily functions.	Requiring the use of PPE as an SOP.
4.	Warehouse control personnel do not wear masks.	Storage warehouse	Storage warehouse	inhaling air in the warehouse space.	shortness of breath, bitter throat radiation.	Create strict policies and standard operating procedures (SOPs) that require the use of masks while in the warehouse and prepare masks in a safe place from radiation.
5.	Sloping Activities.	Demilitarization Workshop	Demilitarization Workshop	Inhaling additive gas, hot steam, hot water splashes, hot TNT.	Shortness of breath, bitter throat, radiation, dizziness & blisters.	Classification of high-security ammunition as specified, strictly implementing SOP, mandatory use of PPE and masks

* Risk assessment in ammunition storage warehouses can be classified in table 4.

TABLE IV. RISK ASSESSMENT IN AMMUNITION STORAGE WAREHOUSES

No	Demilitarization Activity Identification	Risk Assessment		Risk Level
		Frequency	Severity	
1.	Temperature and humidity verification	Checks are carried out once a week	It can cause material and life losses.	High Risk.
2.	Ammunition material transportation process	Done at the time of ammunition request	It can cause material and human losses	High Risk.
3.	Personnel not wearing PPE at certain times.	carry out the demilitarization process	It can cause material and human losses	High Risk.
4.	Warehouse storage control does not wear masks	Checks are carried out once a week	Long-term causes of chronic disease or poisoning	High Risk.
5.	Sloping Activities.	Demilitarization workshop	Causes burns, poisoning, radiation to the throat, and chronic diseases.	High Risk.

Based on the calculations of material capacity values to support demilitarization activities through the sloping method and the results of risk identification obtained by applying HIRADC at the Ammunition Storage Depot, it was analyzed that demilitarization activities require readiness in supportive materials and an optimal implementation process for the best possible outcomes.

The application of HIRADC, following the analysis on each Hazard Identification, Control Determination, and Risk Assessment table, shows that hazards in the ammunition storage warehouse present high-risk work conditions. The risks primarily stem from human error or natural factors, potentially causing significant harm to personnel, materials, and the environment. Therefore, strict adherence to SOP implementation is essential during ammunition demilitarization activities.

VI. CONCLUSION

The demilitarization of ammunition and explosives is a complex process that requires meticulous planning, technical expertise, and stringent safety protocols. This process follows a structured approach encompassing inventory assessment, method selection, asset preparation, implementation, risk management, and post-processing evaluation.

Risk management in the demilitarization of stored ammunition and explosives involves comprehensive risk identification and a structured assessment of potential hazards posed during the demilitarization process to personnel, facilities, and the surrounding environment. Operational safety can be significantly enhanced by implementing effective controls to reduce the likelihood of hazardous incidents.

These findings represent a critical contribution to the risk management literature on ammunition handling, providing a more cautious and adaptive approach to managing risk variations. Moreover, the ramp method used in the demilitarization process has demonstrated high effectiveness in minimizing radiation risks and other related accidents, particularly during critical stages of ammunition demilitarization. This approach is recommended for widespread application in ammunition storage facilities with similar activities to continuously and sustainably improve overall safety standards.

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