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TABLE OF CONTENTS

No.	AUTHORS	PAPER	PAGES
1.	Xuan-Nam Bui, Tran Quang Hieu, Nguyen Anh Tuan, Do Ngoc Hoan, Nguyen Phu Vu, Le Van Quyen	Training and Scientific Research Orientation in Surface Mining: Steadfast Integration, Reaching New Heights in the Modern Era	1-14
2.	Nguyen Anh Tuan, Pham Van Viet, Pham Van Hoa, Do Ngoc Hoan, Tran Dinh Bao	Stone in Vietnam: Building stone, rock fill and armourstone in construction for Sustainable Development	15-23
3.	Xuan-Nam Bui, Carsten Drebenstedt, Nguyen Hoang, Nguyen Van Duc, Tran Quang Hieu, Nguyen Quoc Long, Le Ngoc Ninh	Smart Mining - Opportunities and Challenges for Vietnam's Mining Industry	24-41
4.	Lai Hong Thanh, Mai The Toan, Le Ngoc Ninh, Xuan-Nam Bui	Vietnam's 2024 Law on Geology and Minerals: Opportunities and Challenges for the Mining Industry	42-55
5.	Le Thi Thu Hoa, Nguyen Hoang, Tran Quang Hieu, Tran Dinh Bao, Le Qui Thao, Nguyen Truc Anh, Atrushkevich Victor, Xuan-Nam Bui	Some Technological Approaches, Optimization Strategies, and Sustainable Development Directions for Selective Mining in Vietnam's Open-Pit Coal Mines	56-66
6.	Le Qui Thao, Do Ngoc Le Dung, Nguyen Thi Thuc Anh, Do Ngoc Hoan, Xuan-Nam Bui	Some Technological Orientations for Safe and Environmentally Friendly Mining Technology of Coastal Placer Titanium Deposits in Vietnam	67-83
7.	Tran Quang Hieu, Nguyen Van Duc, Xuan-Nam Bui, Trinh Hai Son, Bui Hoang Bac	Sustainable Rare Earth Mining Technologies: Global Trends and a Tailored Model for Vietnam's Development	84-98
8.	Tran Quang Hieu, Xuan-Nam Bui, Le Ngoc Ninh, Bui Hong Quang, Nguyen Van Hai	The management and utilization of industrial explosives in Vietnam: Achievements, opportunities, challenges, and future development orientations.	99-110
9.	Thang Dam Trong, Duc Ngo The	Experimental investigation on the influence of water saturation on the propagation velocity of blasting stress waves	111-123
10.	Nguyen Dinh An, Tran Dinh Bao	Controlling Harmful Impacts of Rock Blasting for Construction Site Preparation in Ha Giang Province, Vietnam	124-136
11.	Ngo Ngoc Thuy, Dam Trong Thang	A Study on Mitigating Air Shock Wave Intensity in Surface Blasting for Rock Fragmentation Using Sand Cover Layers	137-148
12.	Van-Viet Pham, Pirat Jaroonpattanapong, Nguyen Anh Tuan, Van -Hoa Pham	Prediction of an appropriated powder factor used for blasting under the consideration of blast direction and rock mass quality	149-163
13.	Tung Lam Vu, Quang Hieu Tran, Trong Hieu Vu	Investigation and Analysis for the Selection of an Appropriate Method to determine Rock fragmentation from Experimental Data	164-175
14.	Do Ngoc Hoan, Tran Quang Hieu, Tran Dinh Bao	Achievements and Challenges in Occupational Safety and Health Management in the Mineral Mining industry in Vietnam	176-189
15.	Lam Kieu Anh, Tran Quang Hieu, Do Ngoc Hoan, Nguyen Anh Tho, Do Thi Lan Chi	Assessment and Control of Fire and Explosion Risks in Industrial Explosives Storage Facilities	190-209

• 16.	Do Van Trieu, Tran Dinh Bao, Dang Tien Anh, Dinh Ba Lam, Nguyen Van Hoang	Overview of Carbon Storage Technologies in Mine Waste Rock: Opportunities and Challenges for TKV Open-Pit Mines	210-223
17.	Do Thi Lan Chi, Vu Van Thu, Do Ngoc Hoan	Safety Culture In Enterprises: An Assessment And Intervention Framework Based On A Multi-Model Approach	224-233
18.	Xuan-Nam Bui, Thi-Tam Nguyen, Ngoc-Ninh Le, Duc-Tin Quach, Quang-Hieu Tran, Chang-Woo Lee, Van-Trieu Do, Van-Duc Nguyen	Decarbonizing Vietnam's Open-Pit Coal Mining: A Life Cycle Case Study of Emissions and Mitigation Pathways	234-248
19.	Tuan-Ngoc Le, Nguyen Truc Anh, Hoang Nguyen, Xuan-Nam Bui	Predicting PM2.5 Concentrations in an Open-Pit Copper Mine Using Advanced AI Techniques: Insights from the Sin Quyen Copper Mine, Vietnam	249-268
20.	Léopold Dupuy, Nguyen Mai Anh, Hoang Nguyen	Soil Organic Carbon Assessment and Prediction in Rehabilitated Open-Pit Mining Areas Using GIS and Machine Learning: Insights from France	269-290
• 21.	Tran Dinh Bao, Vu Van Thu	Analysis, evaluation, and proposal of solutions to enhance the effectiveness of occupational safety and health practices in Vietnam in the current period	291-312
22.	Do Duc Thanh, Ngo Thanh Tuan	Impact of large capacity solar power sources when connected near high-voltage power system supplying electricity to mining areas	315-320
23.	Nguyen Hoang Long, Xuan-Nam Bui, Tran Thi Hai Van, Dinh Bao Ngoc, Tran Truong Giang	Development of a Management and Monitoring System for Production Activities in Open-Pit Quarries in Vietnam	321-328
24.	Dam Trong Thang, Nguyen Chi Ta, Vu Chong Hieu, Le Hong Hai	Improvement of the Method for Determining the Specific Explosive Consumption for Rock Destruction under Water by a Charge in a Borehole, Based on the Rock Failure Mechanism Induced by Reflected Stress Waves	329-342
25.	Nguyen Van Tinh, Dam Trong Thang, Le Sy Thuong, Tran Quang Hieu	Study of the calculation, design, and fabrication of rational small explosive charges for experimental research on soil and rock blasting using miniature models	343-358
26.	Nguyen V.H, Dam T.T, Nguyen V.I, Tatarinov V.V, Tran V.L	Experimental Study of Noise Reduction Solutions in an Electric Explosion Device Model	359-374
27.	Nguyen Manh Thuong, Dam Trong Thang, Ta Quang Yen	Esearch, Fabrication and Testing of an Assembled Floating Working Platform for Underwater Drilling of Blast Holes in Marine Conditions in Quang Ninh Province	375-385
28.	Nguyen Anh Tuan, Do Ngoc Hoan, Pham Van Viet, Tran Quang Hieu	Proposing fundamental criteria for open-pit mining to ensure efficiency, sustainability, and climate change adaptation in Vietnam	386-395
29.	Tran Quang Hieu, Nguyen Anh Tuan, Do Ngoc Hoan, Xuan -Nam Bui, Nguyen Van Duc	The future of open-pit mining in Vietnam: opportunities, challenges, and pathways to sustainability	396-412
30.	Le Duc Phuong , Do Ngoc Hoan, Phi Trung Kien	Methodology for rational determination of ultimate pit limits for monometallic and polymetallic mines managed by TKV	413-422
• 31.	Nguyen Anh Tuan, Pham Van Viet, Tran Trung Anh, Nguyen Van Tinh, Tran Dinh Bao, Pham Minh Tu, Noelle Escutenaire	Run-of-mine ore quality homogenization: Application for mining conditions of block 24-122, Tan Rai bauxite mine, Tay Nguyen	423-431

- 32. Nguyen Anh Tuan, Pham Van Viet, Tran Trung Anh, Tran Dinh Bao, Pham Van Hoa Hoa, Phạm Minh Tu, Noelle Escutenaire Bauxite ore grade model: construction of a resource and grade distribution map for block 24-122, Tan Rai bauxite mine 432-440
- 33. Khuong The Hung, Bui Hoang Bac Vu The Thu Sustainable development of apatite ore at the Coc mine, Lao Cai province based on a comprehensive assessment of geological conditions and mining status 441-447
- 34. Le Ba Phuc, Do Van Trieu, Dang Tien Anh, Tran Dinh Bao Study on developing a method for monitoring the load model on dump trucks transporting overburden at open-pit mines for digital transformation 448-459
- 35. Do Ngoc Tuoc, Nhu Viet Tuan, Trinh Thi Phuong Assessment of the Potential for Microbial Underground Coal Biogasification in the Red River Delta Coal Basin 460-469
- 36. Dam Quang Sang, Nguyen Van Tinh, Hoang Trung Huu, Nguyen Ngan, Tran Van Dung, Tran Quang Hieu Method for Determining Detonator Parameters for Blasting in Open-Pit Mines in Vietnam 470-479
- 37. Pham Van Hoa, Tran Van Dung, Hoang Anh Phong, Trinh Quang Trung, Le Van Quyen, Duong Thanh Trung, Tran Dinh Bao, Tran Quang Hieu, Nguyen Anh Tuan, Nguyen Dinh An, Pham Van Vie Drilling and blasting operations management system – designed to meet digital transformation requirements and adapted to practical conditions of Open-Pit coal mines in Quang Ninh region 480-490
- 38. Doan Van Thanh, Do Van Trieu, Dinh Ba Lam, Tran Dinh Bao Study on simulating the propagation of blasting stress waves in water-saturated rock and soil conditions at coal mines under TKV 491-500
- 39. Hoang Manh Thang, Doan Van Thanh, Dinh Ba Lam, Dang Tien Anh Research on Non-Explosive Rock Breaking Methods for Open-Pit Mines in Vietnam 501-510
- 40. Luu Van Thuc, Do Van Trieu, Le Ba Phuc, Le Thi Thu Hoa The necessity of researching and developing a monitoring database and a slope stability warning program for pit walls and waste dumps using digital models integrated with artificial intelligence (AI) for open-pit mines under TKV 511-520
- 41. Dao Van Chi , Vu Thai Tien Dung, Phan Mai Linh International experience in mainstreaming environmental protection into mineral resource development and implications for Vietnam 521-527
- 42. Phạm Anh Hai , Nguyen Anh Tuan, Trinh Van Hiep, Pham Hong Thai, Dang Anh Duc Application of CCUS Technology in TKV Thermal Power Plants: Potentials and Prospects (Part I) 528-538
- 43. Nguyen Anh Tuan, Nguyen Xuan Tu, Pham Van Viet, Do Anh Son, Ngo Thanh Tuan, Nguyen Tien Hung. Impact assessment of open-pit mining on underground mine structures: A case study of coking coal mining, Bac Lang Cam, Thai Nguyen provinc 539-556
- 44. Nguyen Dinh An , Nhu Van Bach, Tran Dinh Bao Real - Time Blasting Plans Generation Using Artificial Intelligence: Improving Efficiency and Safety in Mining Blasting Operations 557-564



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Assessment and Control of Fire and Explosion Risks in Industrial Explosives Storage Facilities

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ABSTRACT

One of the advances in surface mining aimed at environmental protection and sustainable development is the increasingly emphasized management of industrial explosives (IE) safety. This paper focuses on assessing fire and explosion risks in industrial explosives storage facilities by applying a risk matrix model, while also comparing the findings with international safety management practices. The study identifies the main hazards leading to fire and explosion in IE storage, such as electrical faults, lightning strikes, static electricity, human errors, and environmental factors. Risk levels are classified based on the likelihood of occurrence and the severity of consequences, ranging from low to high, and appropriate control measures are proposed for each risk category. Based on the research results, the paper proposes the development of a systematic risk assessment framework specifically for IE storage facilities in Vietnam, based on national technical standards and international best practices, aiming to enhance fire and explosion safety, improve technical regulations, strengthen management and training, and thereby improve overall risk management effectiveness in IE storage, ensuring the safety of workers and surrounding communities.

Keywords: Occupational Safety and Health, Industrial explosives

1. Introduction

Industrial explosives (IE) are specialized materials widely used in mining, construction, and defense, yet they inherently carry a high risk of fire and explosion if not managed and stored in accordance with safety regulations. The first stage in mineral extraction involves preparing the rock and ore, which means separating the rock and ore from the original block and breaking them into specific sizes to facilitate subsequent handling, transportation, and processing. Rock and ore can be prepared through various methods, including mechanical, physical, or chemical processes; however, the combined drilling–blasting method is considered a common approach, as it meets production requirements while minimizing operational costs. The reaction of explosives is fundamentally a redox reaction, in which carbon and hydrogen act as fuel while the oxygen in the mixture serves as the oxidizer. An explosive reaction can be triggered by external stimuli such as electrical, mechanical, or thermal energy (Ho, et.al. 2010), potentially causing an “uncontrolled detonation.” In particular, any leakage of explosives can pose threats to security,

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politics, and national defense. Therefore, from production to loading at blasting sites, IE must be handled according to a strict process of storage, transportation, and usage. Among these, the storage of explosives in magazines is an especially critical stage.

In practice, even a small mistake in the storage and protection of IE in magazines can lead to incidents and disasters causing human casualties, property damage, loss of security and social order, and environmental impacts. In Vietnam, several notable incidents at IE storage facilities have been reported. For example, on October 12, 2013, an explosion occurred at the storage facility of Z121 Factory (Phu Tho). The blast destroyed the entire factory area spanning tens of thousands of square meters, damaged dozens of residential houses within a radius of over 3 km causing roof collapses and broken windows—and resulted in 24 deaths and nearly 100 injuries. The total financial loss was estimated at VND 50 billion, including VND 20 billion worth of fireworks (<https://thongke.molisa.gov.vn/>). Another case involved a fire at Industrial Explosives Warehouse No. 8, a branch of Quang Ninh Mining Chemical Industry Company. The warehouse contained 199,497 kg of explosives. Although there were no casualties, the fire caused substantial damage to infrastructure and destroyed the entire stock of explosives, estimated at VND 1.4 billion (<https://thongke.molisa.gov.vn/>). Moreover, storing IE in magazines has still allowed criminals to break in, cut locks, and steal explosives and detonators across several provinces (in 2016, 2017, 2018, 2019, 2020, and up to the present), including Hue, Quang Tri, Quang Binh, Thanh Hoa, Quang Ninh, Yen Bai, Lang Son, and Thai Nguyen. The most recent cases include: on January 31, 2024, at the IE warehouse of Thuong Thanh Stone Co., Ltd., in Mai Sao Commune, Chi Lang District, Lang Son Province, a total of 2,475 detonators of various types were stolen; and on September 23, 2024, at the warehouse of Lang Hich Lead-Zinc Enterprise, 2,775 electric detonators were lost due to a break-in (Report on Industrial Explosives Management, Ministry of Industry and Trade).

Internationally, major incidents have also occurred due to unsafe storage of explosive materials. In 2020, two massive explosions at the Port of Beirut, Lebanon, resulted from 2,750 tons of ammonium nitrate being stored unsafely for six years, causing at least 207 deaths, over 7,500 injuries, 10–15 billion USD in damages, and leaving more than 300,000 people homeless (https://vi.wikipedia.org/wiki/V%E1%BB%A5_n%E1%BB%95_Beirut_2020). In 1994, an uncontrolled explosion at the Porgera gold mine in Papua New Guinea created a crater 15 m deep and 40 m in diameter, killing 11 people and affecting a 2 km radius (https://en.wikipedia.org/wiki/Porgera_Gold_Mine).

In Vietnam, the management of safety in IE storage facilities faces numerous challenges. As of 2020, there were 1,282 licensed IE warehouses nationwide, scattered across various stone mining and construction enterprises. Although this number has decreased from 2,116 warehouse clusters in 2010, it remains substantial and fragmented, particularly in certain provinces such as Thanh Hoa (approximately 130 warehouses), Nghe An (around 100 warehouses), Cao Bang (90 warehouses), and Hoa Binh (66 warehouses), among others. The proliferation of small, dispersed warehouses complicates management and increases the risk of safety incidents, loss or theft of explosives, and breaches of public security if not rigorously monitored. Moreover, many incidents in IE storage facilities stem from insufficient investment in safety measures, low compliance awareness among some enterprises, and inadequately trained or inexperienced warehouse personnel, leading to negligence in fire and explosion prevention. This issue is particularly pronounced in small or temporary warehouses, where

owners often overlook essential systems such as lightning protection, static electricity control, and firefighting equipment, thereby further elevating the risk.

In this context, the need to assess and control fire and explosion risks in IE storage facilities has become imperative. This is a critical step to prevent disasters, safeguard the lives of workers, protect company assets, and ensure public safety. Risk assessment enables the accurate and comprehensive identification of potential hazards and the corresponding risk levels of IE, thereby providing a basis for appropriate control measures.

Based on these practical requirements, the objectives of this study are:

1. To identify the main hazards associated with the storage of IE in magazines in Vietnam;
2. To evaluate the corresponding risk levels using a risk matrix method;
3. To compare the results with existing studies, standards, and safety regulations in Vietnam;
4. To propose feasible risk control measures aimed at improving occupational health and safety management in IE storage facilities across Vietnam.

2. Theoretical Basis and Research Methodology

2.1. Legal and Technical Foundations

2.1.1. Regulations on the Storage of Industrial Explosives in Mining Warehouses

Table 1: Legal and Regulatory Documents Related to the Storage of Industrial Explosives

Field	Key Legal Documents	Main Provisions Related to the Storage of Industrial Explosives
Chemicals	- Law on Chemicals 69/2025/QH15 (effective 2026) - Decree 113/2017/ND-CP (expires 2026) - Decree 82/2022/ND-CP - Circular 32/2017/TT-BCT - Circular 17/2022/TT-BCT - Directive 03/2013/CT-TTg - Decision 26/2016/QD-TTg - Decision 04/2020/QD-TTg	- Requirement to report incidents and thefts to local police and People's Committees; production of chemicals near residential areas, public works, water sources, and main transportation routes must be monitored. - Promote green and sustainable technologies, replacing hazardous chemicals with environmentally friendly alternatives. - Guidance on emergency response for chemical accidents, preparation of emergency response plans, and regular training and drills for workers.
Industrial Explosives Management	- Law 42/2024/QH15 - Decree 149/2024/ND-CP - Decree 181/2024/ND-CP - Vietnam Standard 01:2019/BCT	- Strict management of production, storage, use, and disposal of industrial explosives. All activities must be licensed and controlled according to legal authority. - Standards for warehouse safety and storage conditions. Warehouses must be located at safe distances from residential areas, schools,

Field	Key Legal Documents	Main Provisions Related to the Storage of Industrial Explosives
	- Circular 23/2024/TT-BCT - Circular 32/2019/TT-BCT	hospitals, critical infrastructure, and water sources as specified.
Fire Prevention and Rescue	- Law 55/2024/QH15 - Decree 144/2021/ND-CP - Decree 105/2025/ND-CP - Circular 36/2025/TT-BCA	- Firefighting systems required in IE warehouses, including automatic fire alarms, on-site firefighting equipment (fire extinguishers, hydrants, fire pumps), arranged according to Ministry of Public Security standards. - Regulations on penalties for fire and explosion violations, with administrative fines according to severity. - Strengthen rescue and emergency response for incidents; develop specific rescue plans for IE warehouses, including scenarios for fire, collapse, and chemical leaks.
Environmental Protection	- Law on Environmental Protection 72/2020/QH14 - Decree 08/2022/ND-CP, Decree 05/2025/ND-CP - Circular 02/2022/TT-BTNMT, Circular 07/2025/TT-BTNMT - Vietnam Standard 07:2009/BTNMT	- Management of waste from storage and use of IEs. Develop waste management plans, temporary storage, prohibiting illegal dumping, open burning, or burial. - Control environmental impacts from mining warehouses. Submit Environmental Impact Assessment (EIA) reports and periodic environmental monitoring reports. - Assess and classify hazardous waste; labeling, registration, composition analysis, and processing via specialized units.
Occupational Safety and Health (OSH)	- Law on OSH 84/2015/QH13 - Decree 44/2016/ND-CP - Circular 36/2019/TT-BLDTBXH - Circular 06/2020/TT-BLDTBXH	- Periodic inspection of equipment. Warehouse and transport equipment for IEs must be inspected by licensed organizations, with certification tags and complete records. - Safety training for warehouse managers and operators. - List of tasks with strict OSH requirements.

2.1.2. Classification of Industrial Explosives by Hazard Properties

Explosives stored in mining warehouses in Vietnam primarily belong to hazard divisions 1.1 and 1.5D, based on applicable legal documents and current technical standards, such as Vietnam Standard QCVN 01:2019/BCT, Circular 23/2024/TT-BCT, and other relevant national standards.

Table 2: Inventory of Explosive Types with Their Physicochemical Properties and Toxicity (Ho and Bui, 2010)

No	Name	Physicochemical Properties	Toxicity
1	AD1 Explosive (Division 1.1D) 	Composition: • Trinitrotoluene ($C_7H_5O_6N_3$): $(14 \pm 0.5) \%$ • Ammonium nitrate (NH_4NO_3): $(82 \pm 1.0) \%$ • Wood powder: $(4 \pm 0.5) \%$ • Moisture content: $\leq 0.3\%$ Density: $0.95 - 1.15 \text{ g/cm}^3$ Detonation velocity: $3,600 - 4,200 \text{ m/s}$ Gas volume (work capacity): $340 - 360 \text{ cm}^3$ Lead cylinder compression strength: $14 - 16 \text{ mm}$ Detonation transmission distance: $3 - 7 \text{ cm}$	Material Hazards: • Risk of fire and explosion; potential for mass detonation. Health Hazards: • Toxicity: May cause abdominal discomfort, pain, diarrhea, vomiting, and nausea. • Eye effects: May cause irritation and temporary vision impairment. • Skin effects: May cause irritation and redness in sensitive skin. • Respiratory effects: May induce nausea, dizziness, and fatigue. Environmental Hazards: • Harmful to aquatic organisms.
2	ANFO Explosive (Division 1.5D) 	Composition: • Porous ammonium nitrate: $94 - 96\%$ • Diesel fuel: $4 - 6\%$ Appearance: Solid granules, white or red for identification due to colored fuel. Melting point: Not applicable Boiling point: Not applicable Vapor pressure: Not applicable Density: $0.8 - 0.9 \text{ g/cm}^3$ Detonation velocity: $3,500 - 4,000 \text{ m/s}$ Detonation energy (gas volume): $320 - 330 \text{ cm}^3$ Sensitivity to initiation: Sensitive to blasting cap Water resistance: Non-water-resistant	Material Hazards: • Risk of fire and explosion; potential for mass detonation. Health Hazards: • Toxicity: May cause abdominal discomfort, pain, diarrhea, vomiting, and nausea. • Eye effects: May cause irritation and temporary vision impairment. • Skin effects: May cause irritation and

No	Name	Physicochemical Properties	Toxicity
		Shelf life: 3 months Flash point: Not applicable Flammability limits: Not applicable Solubility in water: Soluble in water	redness in sensitive skin. - Respiratory effects: May induce nausea, dizziness, and fatigue. Environmental Hazards: - Harmful to aquatic organisms.
3	Emulsion Explosive for Open-Pit Mining (Division 1.5D) 	Composition: - Oxidizing agent (nitrate salts): 70 – 100% - Fuel oil: 0 – 10% - Other non-hazardous components: Added to make up 100% Appearance: Light yellow to gray, paste-like consistency. Melting point: Not applicable Boiling point: Not applicable Vapor pressure: Not applicable Density: 1.05 – 1.20 g/cm ³ Detonation velocity: ≥ 4,100 m/s Sensitivity to initiation: Sensitive to detonators of strength No. 8 Water resistance: ≥ 12 hours Shelf life: 6 months Flash point: Not applicable Flammability limits: Not applicable Solubility in water: Insoluble, but dispersible under strong agitation	Material Hazards: - Risk of fire and explosion; potential for mass detonation. Health Hazards: - Toxicity: May cause abdominal discomfort, pain, diarrhea, vomiting, and nausea. - Eye effects: May cause irritation and temporary vision impairment. - Skin effects: May cause irritation and redness in sensitive skin. - Respiratory effects: May induce nausea, dizziness, and fatigue. Environmental Hazards: - Harmful to aquatic organisms.
4	Emulsion Explosive for Underground Mining without Gas and Dust (Division 1.5D)	Composition: - Oxidizing agent (nitrate salts): 70 – 100% - Fuel oil: 0 – 10% - Other non-hazardous components: Added to make up 100% Appearance: Light yellow to gray, paste-like consistency.	Material Hazards: - Risk of fire and explosion; potential for mass detonation. Health Hazards: - Toxicity: May cause abdominal discomfort, pain, diarrhea, vomiting,

No	Name	Physicochemical Properties	Toxicity
		Melting point: Not applicable Boiling point: Not applicable Vapor pressure: Not applicable Density: 1.05 – 1.20 g/cm ³ Detonation velocity: ≥ 4,100 m/s Sensitivity to initiation: Sensitive to detonators of strength No. 8 Water resistance: ≥ 12 hours Shelf life: 6 months Flash point: Not applicable Flammability limits: Not applicable Solubility in water: Insoluble, but dispersible under strong agitation Other properties: Not established	and nausea. - Eye effects: May cause irritation and temporary vision impairment. - Skin effects: May cause irritation and redness in sensitive skin. - Respiratory effects: May induce nausea, dizziness, and fatigue. Environmental Hazards: - Harmful to aquatic organisms

2.2. Research Methodology

2.2.1. Data Collection and Literature Review

Data collection involved gathering current legal documents, regulations, and Viet Nam standards related to the storage of IE, as well as scientific reports and previous studies relevant to mine warehouse safety. In addition, technical documents from enterprises and guidance from international organizations were consulted to ensure the comprehensiveness and up-to-dateness of the research content.

2.2.2. Field Survey

Direct surveys were conducted at several mine warehouses of varying sizes storing explosives at enterprises engaged in mineral exploitation in Vietnam. The survey contents included: the current state of warehouse infrastructure, storage conditions, fire and explosion prevention systems, management and operational practices, and actual compliance with safety regulations. Survey results were documented on-site through risk assessments related to occupational safety and health (OSH), warehouse security, the scope of the affected area, and the identification of entities requiring protection in the vicinity of the mine warehouses.

2.2.3. Expert Consultation

In-depth interviews and consultations were conducted with experts experienced in the management and use of industrial explosives, personnel directly involved in warehouse management, and scientists in the fields of OSH and mining. Expert opinions were used to cross-check, verify, and supplement findings from field surveys and literature analysis, forming the basis for assessing risk levels during the evaluation process.

2.2.4. Risk Matrix Method for Hazard Identification and Risk Assessment

The identification and assessment of occupational safety and health risks associated with hazards in industrial explosive warehouses were performed using a point-based risk matrix method. The risk level of hazards was evaluated based on scoring criteria including: the

frequency of hazard occurrence, the severity of potential injuries, and the detectability of hazards. The risk matrix method is based on the following formula:

$$\text{Risk Level} = \text{Probability} \times \text{Impact}$$

The levels and scoring methods for risk according to specific criteria are presented in the following tables:

Table 3: Criteria for Estimating the Frequency of Hazard Occurrence

Rating Level	Specific Criteria Description	Score (1-5)
Rare	Very unlikely to occur; estimated about once every 2-3 years	1
Unlikely	Very low likelihood; on average about once per year	2
Moderate	Moderate likelihood; estimated about once per month	3
Likely	High likelihood; event occurs frequently on a weekly basis	4
Almost Certain	Almost certain to occur; event occurs very frequently (nearly daily)	5

Table 4: Criteria for Estimating Injury Consequences

Rating Level	Specific Criteria Description	Score (1-5)
Negligible	Does not cause injury or serious illness	1
Minor	May cause minor injury or illness	2
Moderate	May cause injury or illness requiring medical attention but limited treatment	3
Serious	May cause irreversible injury or illness, requiring continuous medical care	4
Critical	May result in fatality	5

Table 5: Risk Assessment Criteria Using a 5x5 Risk Matrix

Rating Level	Specific Criteria Description	Risk Level
1-4	Acceptable – no further action required; recommended to maintain existing control measures	I
5-9	Sufficient – may be considered for further analysis	II
10-16	Tolerable – should be reviewed in a timely manner to implement improvement strategies	III
17-25	Unacceptable – immediate cessation and confirmation of corrective actions required	IV

Table 6: Proposed Classification of Risk Levels

Consequence Frequency	1	2	3	4	5
5	II (5)	III (10)	III (15)	IV (20)	IV (25)
4	II (4)	II (8)	III (12)	III (16)	IV (20)
3	I (3)	II (6)	II (9)	III (12)	III (15)
2	I (2)	I (4)	II (6)	II (8)	III (10)
1	I (1)	I (2)	I (3)	II (4)	II (5)

3. Explosion and Fire Risk Assessment in Industrial Explosives Storage Facilities

Through the identification process, six main hazard categories were determined in the explosives storage facilities:

Table 7: Classification of Hazard Groups in Explosives Storage Facilities

No.	Hazard Group	Specific Hazards
1	Physical	Fire and explosion caused by impact, friction, static electricity, mechanical or electrical sparks.
2	Chemical	Reactions between explosive components or between explosives and impurities, chemical vapors.
3	Mechanical – Equipment	Forklifts, lighting not meeting explosion-proof standards, collisions during explosive handling.
4	Human	Operational errors, non-compliance with regulations, lack of training.
5	Environmental	High temperature, high humidity causing deterioration of explosive quality, leading to risk of spontaneous detonation.
6	Security – Social	Theft, sabotage, unauthorized access.

The underlying causes, derived from the main hazard categories above, were further broken down and analyzed by the research team, as presented in Table 8.

Table 8: Analysis of Risk Causes in Explosives Storage Facilities

No.	Incident Code	Incident Name	Causes
1	SC1	Spillage of explosives in storage area	1. Subjective causes: - Errors during transportation; - Improper stacking or unloading on racks/pallets; staff not following proper techniques, leading to spillage. 2. Objective causes: - Impact from other incidents; - Damaged packaging during transport. 3. Natural causes: - Storms, earthquakes, landslides causing racks to collapse. 4. Human causes: - Sabotage activities.
2	SC2	Fire or explosion in storage area	1. Subjective causes: - Lightning protection system deteriorated, ineffective grounding, storage struck by lightning causing fire/explosion; - Grounding resistance measurement devices malfunction, not properly assessing the lightning system; - Safety violations: uncontrolled introduction of matches, lighters, radio-emitting devices by employees or visitors into the warehouse; - Accidental friction caused by tools during vegetation clearing or handling incidents; - Firefighting equipment (e.g., 8 kg explosive charges) non-functional during incidents. 2. Objective causes: - Fire or explosion from outside spreading into the warehouse; - Forest fires nearby; - Burning leaves or debris nearby spreading to warehouse; - Impact from other warehouse incidents. 3. Natural causes: - Storms, earthquakes, landslides, floods. 4. Human causes: - Sabotage. - Frequency: rare.

No.	Incident Code	Incident Name	Causes
3	SC3	Spillage of explosives during internal transport	- Accidents during internal transport; - Impact from other incidents: storms, earthquakes, landslides, fires/explosions at other warehouses; - Sabotage. - Frequency: possible.
4	SC4	Fire or explosion in transport vehicles	- Transport accidents; - Vehicles not meeting technical regulations (QCVN 01:2019/BCT), causing sparks or fire; - Impact from other incidents: storms, earthquakes, landslides, warehouse explosions; - Sabotage. - Frequency: rare.
5	SC5	Collision causing vehicle to lose control and hit storage area, risk of fire/explosion	- Transport accidents; - Vehicles not meeting technical regulations (QCVN 01:2019/BCT), causing sparks/fire; - Impact from other incidents: storms, earthquakes, landslides, warehouse explosions; - Sabotage. - Frequency: rare.
6	SC6	Prolonged rain/flooding causing water ingress, carrying explosives into environment	- Heavy rain over several days combined with weathering making soil unstable; - Strong storms; - Flash floods, debris flows; - Clogged warehouse drainage system.
7	SC7	Improper warehouse layout	- Poorly positioned warehouses affecting surrounding population or structures during incidents; - Adjacent warehouses can be affected during incidents; - Improper stacking inside warehouse leading to chain incidents during storage.
8	SC8	Improper warehouse construction, lighting, ventilation	- Collapsing walls or structures; - Insufficient lighting causing operational errors; - Poor ventilation affecting explosive quality.

No.	Incident Code	Incident Name	Causes
9	SC9	Improper equipment use in warehouse causing fire/explosion or spillage	- Non-compliant equipment causing collisions or electrical sparks; - Electrical short circuits, fuel leaks causing fire/explosion risk; - Spillage during handling operations.
10	SC10	Workers lacking expertise or insufficient training	- Workers not following procedures leading to errors; - Insufficient safety training limiting ability to apply safe work practices.
11	SC11	Unsuitable environmental conditions	- High humidity affecting explosive quality and causing spontaneous detonation; - Excessive ambient temperature causing risk of spontaneous detonation.
12	SC12	Inadequate security system, unsafe receipt/issuance procedures	- Weak fences/security allowing unauthorized access; - Lack of continuous CCTV monitoring; - Improper procedures for receiving and issuing explosives leading to loss or fire/explosion.

Table 9. Risk Assessment of Accidents at Explosive Storage Facilities

No.	Incident Code	Frequency	Consequence	Risk Score	Risk Level	Characteristic Risk Type
1	SC1	2	3	6	II	Explosion
2	SC2	2	5	10	III	Fire, Explosion
3	SC3	2	3	6	II	Explosion
4	SC4	2	5	10	III	Fire, Explosion
5	SC5	2	3	6	II	Explosion
6	SC6	2	5	10	III	Fire, Explosion
7	SC7	2	3	6	II	Explosion
8	SC8	2	5	10	III	Fire, Explosion
9	SC9	2	3	6	II	Explosion
10	SC10	2	5	10	III	Fire, Explosion

11	SC11	2	5	10	III	Fire, Explosion
12	SC12	2	4	8	II	Corrosion, Chemical Reaction

Hazards 1, 3, and 5 in the table above are closely related to technical factors (electricity, static electricity, equipment). Therefore, control measures should focus on improving technical safety (compliant equipment, static electricity prevention, etc.). On the other hand, Hazards 4 and 8 are associated with human factors and internal management, requiring solutions in procedures, discipline, and training.

4. Some Specific Measures to Enhance the Effectiveness of Risk Control and Incident Mitigation at Explosives Storage Facilities

4.1. Management-Related Measures

- Management of Explosives Storage: Assign specific responsibilities to individuals in charge of safety at explosives warehouses, including the Director, warehouse managers, and other responsible personnel.

- Responsibilities of the Director: Serve as the focal point for managing the distribution and supply of explosives, oversee company warehouses, and periodically review and adjust management procedures. When necessary, modify procedures to ensure proper implementation and compliance with explosives management regulations. Conduct safety inspections of chemicals before storage. Regularly inspect equipment related to explosives. The company should establish clear procedures for receipt, issuance, distribution, and management of explosives, with steps presented visually and clearly so that operational workers can follow and comply. Organize certification training for employees who handle explosives directly before starting work. Supervise explosives suppliers and report chemical management activities to governmental authorities annually.

- Responsibilities of the Warehouse: Responsible for receiving, storing, and providing explosives to partners according to company requirements. When receiving or issuing explosives, inspect containers for suitability and damage. Store explosives according to technical standards and comply with current legal regulations (QCVN 01:2019/BCT). Ensure all chemical information and MSDS are complete.

- Responsibilities of Suppliers: Must provide complete safety information for each type of explosive supplied to the company. Suppliers must provide evidence of the safety of transport and storage equipment, such as safety inspection certificates for vehicles or storage facilities. Suppliers must ensure that their transport and handling operations comply with company regulations.

- Establishment and Implementation of Internal Regulations for Explosives Management:

1. Fire Prevention and Fighting Regulations for Explosives Warehouses
2. Fire Prevention and Fighting Regulations for Detonator/Accessory Warehouses
3. Access Regulations for Explosives Warehouses
4. Storage Regulations for Explosives in Warehouses
5. Explosives Issuance Regulations
6. Operational Safety Regulations for Fire Pumps
7. Electrical Safety Regulations in Explosives Storage Areas

4.2. Organization of Training, Drills, and Emergency Response Exercises for Risk Incidents

- Organize training, assessments, and certification for personnel, including management staff and workers who directly handle or are exposed to hazardous chemicals, in accordance with legal regulations.

- Personnel directly involved in warehouse security, explosives receipt, issuance, and transportation must receive certified training in chemical safety, explosives safety, fire prevention and fighting, security operations, and the use of supporting tools.

- Conduct training on fire safety for chemicals stored in warehouses and organize drills for simulated emergency scenarios in accordance with the Fire Prevention and Fighting Law and the Ministry of Public Security regulations, including safe management and handling of explosives and explosive precursors.

- Organize training, education, and knowledge assessments on chemical safety in compliance with relevant regulations.

- Conduct fire prevention and fighting drills based on the established FPFF plan (once per year) and organize chemical emergency response drills (once per year).

4.3. Organization of Inspections and Monitoring to Mitigate and Control Risks

- Develop inspection and monitoring plans focusing on the following groups: storage racks and platforms for explosives; electrical equipment; lightning protection systems; the amount of sand and water in firefighting tanks at the far end of each warehouse; firefighting tools placed in the tool room and at the far end of each warehouse; diesel pumps and electric firefighting pumps at the fire pump station; firefighting water tanks and water levels within the tanks; and water quantity in the firefighting ponds.

- Monitor suppliers to prevent external risks. Cooperation will be refused with suppliers who fail to comply with safety requirements as per regulations.

4.4. Organization of Security, Duty, and 24/7 Guarding

- Establish guard posts and assign security personnel in shifts, with clear regulations on entry and exit to the explosives warehouse area, and maintain a log of all personnel entering and leaving the warehouse.

- Conduct patrols and inspections to monitor any irregularities, 24/7. Each patrol team should consist of 2 personnel, with teams rotating to cover the warehouse perimeter.

- Confiscate mobile phones, devices emitting electromagnetic or radio waves, lighters, matches, and any tools that may generate friction.

4.5. Classification of Explosives by Explosive Hazard and Compatibility Groups for Storage

In explosives warehouses, they are classified according to their explosive hazard in compliance with Appendix 1 of QCVN 01:2019/BCT. Explosives are categorized into hazard groups 1.1, 1.2, 1.3, 1.4, 1.5, and 1.6, with appropriate warning labels. Additionally, explosives stored in the warehouses are classified according to their compatibility groups (as stipulated in Table 1.2 – Appendix I of QCVN 01:2019/BCT), as shown in the following table.

Table 10. Classification of Explosives by Compatibility Group

Compatibility Group	Type of Explosive	Classification Code
A	Primary explosives	1.1A
B	Accessories containing primary explosives without protective devices (safety mechanisms). Example: Detonators, blasting caps	1.1B, 1.2B, 1.4B
C	Propellant explosives, pyrotechnic substances, or products containing them	1.1C, 1.2C, 1.3C, 1.4C
D	Secondary explosives, black powder, or products containing secondary explosives without detonators and without propellant charges; products containing primary explosives with protective devices	1.1D, 1.2D, 1.4D, 1.5D
E	Accessories containing secondary explosives without detonators but with propellant charges	1.1E, 1.2E, 1.4E
G	Products containing explosives and substances producing light or smoke effects	1.1G, 1.2G, 1.3G, 1.4G

Compatibility Group	Type of Explosive	Classification Code
S	Substances or products packaged or designed so that the hazardous effects arising from an incident are confined within the destroyed packaging due to fire	1.4S

According to the above table, AD1 explosives are classified as 1.1D, while emulsion explosives and ANFO explosives are classified as 1.5D. This information corresponds to the classification codes based on explosive hazard and the associated safety labels for chemicals stored in the warehouse.

In the warehouse, explosives are classified and stored according to their compatibility groups. Incompatible chemicals must not be stored or transported together. The principles defining which groups of explosives are compatible with each other are summarized in the following table:

Table 11. Principles for Compatibility of Explosive (VLNCN) Groups

Group	A	B	C	D	E	G	S
A	X						
B		X		X ⁽¹⁾			X ⁽¹⁾
C			X	X	X	X ⁽²⁾	X ⁽¹⁾
D		X ⁽¹⁾	X	X	X	X ⁽²⁾	X ⁽¹⁾
E			X	X	X	X ⁽²⁾	X ⁽¹⁾
G			X ⁽²⁾	X ⁽²⁾	X ⁽²⁾	X	X ⁽¹⁾
S		X	X ⁽²⁾	X ⁽²⁾	X ⁽²⁾	X ⁽²⁾	X

Note: An “X” indicates that the groups can be stored and transported together.

4.7. Response Plan for Anticipated Chemical Incident Scenarios

Units are required to establish an emergency response force at two levels. Level I incidents will be managed internally within the company. Personnel participating in the response are company staff who have received proper training and can handle low- to medium-severity Level I incidents.

For incidents with high-risk potential, Level II response must be applied, which involves requesting assistance from provincial or municipal emergency response forces. The emergency response procedure for explosives warehouses is carried out according to Diagram 1.

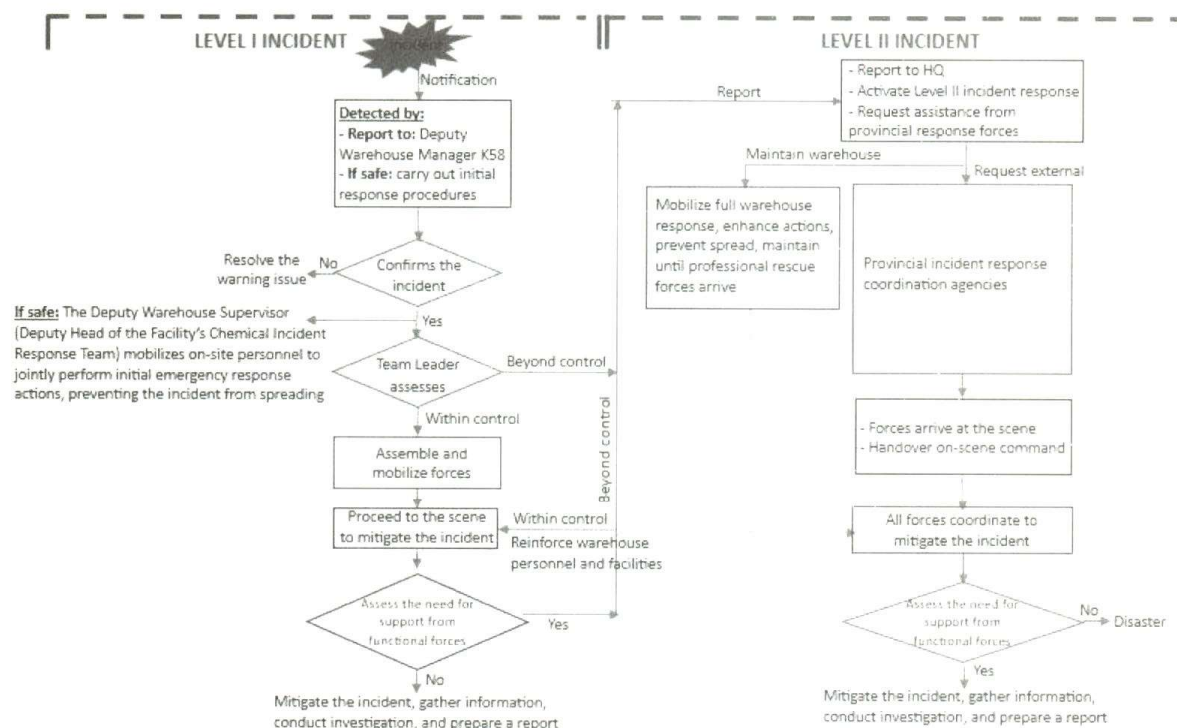


Figure 1. Emergency Response Procedure for Explosives Warehouse

5. Conclusions and Recommendations

5.1. Conclusions

The study has systematically consolidated the theoretical basis, legal framework, and practical aspects related to the storage of industrial explosives in warehouses nationwide. Through field surveys, expert interviews, and the application of the risk matrix method, the research team identified six main hazard groups and twelve potential incident scenarios commonly encountered during explosives storage, including: electrical short-circuit fires and explosions, mechanical impacts, lightning strikes, human errors, adverse environmental conditions, and risks from social security factors.

Risk analysis results indicate that most scenarios carry a medium to high risk level, with notable concerns including warehouse explosions (SC2), transportation vehicle explosions (SC4), inadequate environmental conditions (SC11), non-compliant equipment (SC9), and operator errors (SC10).

The study also proposed a comprehensive set of risk control measures, including enhancing warehouse management capacity, clearly defining responsibilities, providing specialized training, establishing inbound/outbound procedures, strengthening security and fire prevention supervision, classifying explosives according to compatibility levels, and organizing emergency response drills. These measures provide a solid foundation for improving

safety management effectiveness in explosives warehouses, minimizing the likelihood of serious incidents, and ensuring the safety of workers and nearby communities.

5.2. Recommendations

Based on the research findings, the authors recommend the following actions:

1. Enhance the national legal and technical standards for explosives storage, particularly by updating QCVN 01:2019/BCT and issuing detailed guidance on warehouse risk assessment using the risk matrix model.
2. Develop a national explosives warehouse database to enable centralized management, integration with regulatory authorities, early warning systems, and remote inspection and monitoring.
3. Reduce the number of small, temporary warehouses and progressively establish centralized warehouse clusters equipped with modern security, fire prevention, and monitoring systems, meeting high safety standards.
4. Strengthen periodic inspections, equipment certification, and mandatory safety training, especially for warehouse operators, explosives transporters, and personnel directly handling VLNCN.
5. Develop and disseminate a dedicated risk assessment toolkit (Checklist + Risk Matrix) tailored to each warehouse type based on size and explosive category, for practical application within enterprises.
6. Recommend that the Ministry of Industry and Trade collaborate with the Ministry of Public Security and the Ministry of Home Affairs to issue inter-agency guidance on explosives fire and explosion emergency drills, thereby enhancing emergency response capacity.

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Contributions of authors

Lam Kieu Anh conceptualized the study, conducted theoretical research, collected documents and survey data, carried out the risk assessment at the three mining warehouses, and edited and translated the manuscript; Tran Quang Hieu contributed to idea development and drafted Section 1 regarding the urgency of the issue; Do Ngoc Hoan developed Section 4 on

risk control measures at the mining warehouses, provided inputs for Sections 1 and 3 concerning industrial explosives, and assisted in finalizing the manuscript; Nguyen Anh Tho contributed ideas and supported the development of safety control measures in Section 4; Do Thi Lan Chi conducted literature searches, assisted with field surveys, and helped develop the risk identification and assessment procedures.

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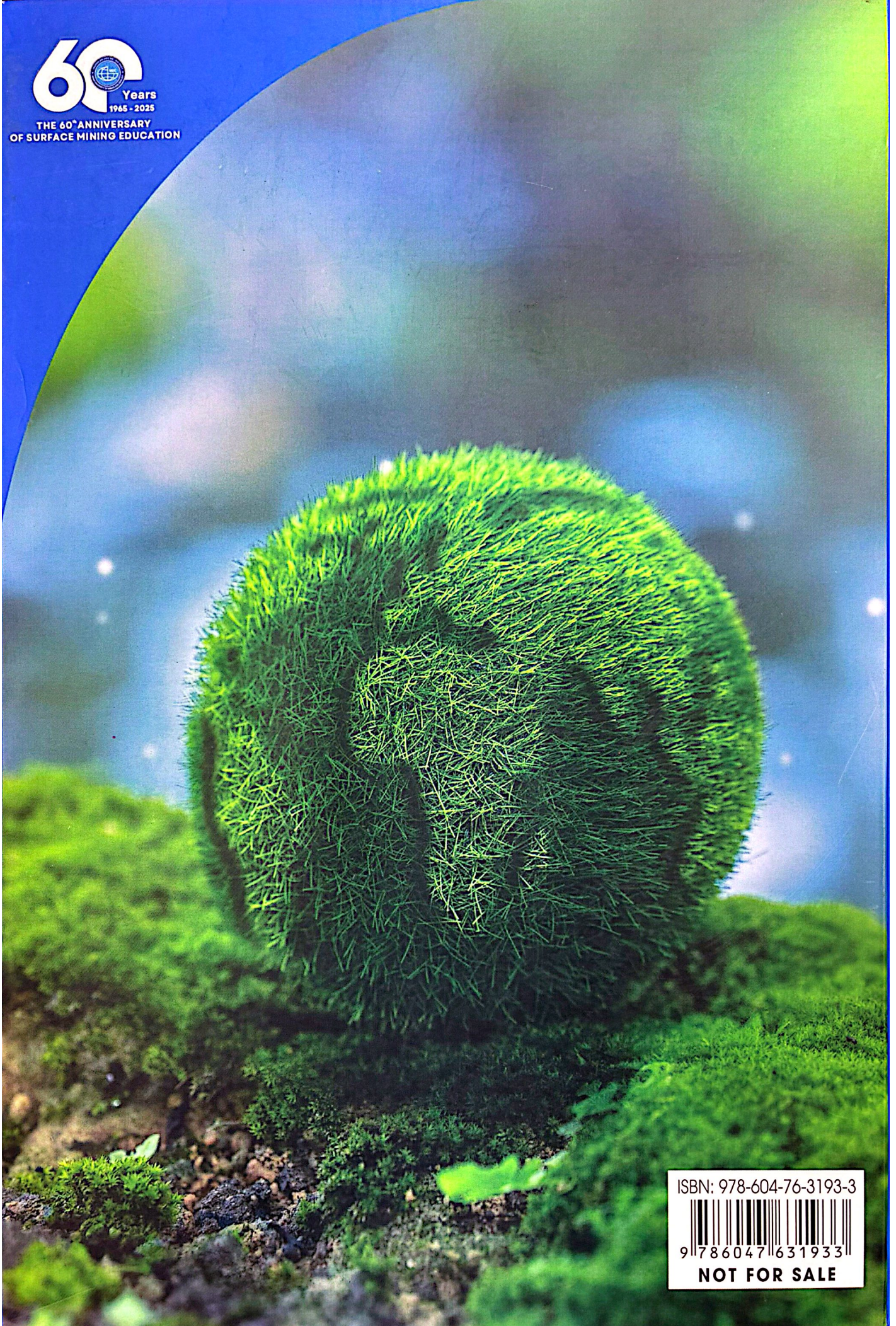
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