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Research on the Storage Management of Explosive-Precursor Chemicals in Engineering University Laboratories

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Abstract

This study systematically analyzes the physicochemical properties and safety risks of 32 categories of explosive-precursor chemicals commonly used in engineering university laboratories. By examining 127 laboratory accident cases reported by the Ministry of Education from 2019 to 2023, it reveals the correlation between management loopholes and accidents. Based on the Regulations on the Safety Management of Hazardous Chemicals and the GB 15603-2022 General Rules for the Storage of Common Hazardous Chemicals, a graded classification storage model and a dynamic supervision system are proposed. The results demonstrate that implementing intelligent storage cabinets and RFID traceability systems can reduce the risk of non-compliant operations by 85%, while establishing a "five-in-one" management system improves the laboratory safety hazard rectification rate to 98.6%. This research provides a standardized solution for the management of hazardous chemicals in university laboratories.

Keywords

Explosive-precursor Chemicals; Laboratory Safety; Storage Management; Engineering Universities; Safety Management System.

1. Introduction

According to the 2023 University Laboratory Safety Report issued by the Ministry of Education [1], hazardous chemical-related accidents account for 63.5% of all laboratory accidents in universities, with incidents involving explosive-precursor chemicals causing approximately 3.8 times more damage than ordinary accidents. Data from the Ministry of Public Security [2] show that from 2018 to 2022, 217 illegal cases related to hazardous chemical management were investigated in universities nationwide, with explosive-precursor chemicals such as ammonium nitrate and peroxides accounting for 79% of these cases. This highlights the urgent need to study the management of explosive-precursor chemicals in university laboratories. Based on the PDCA cycle theory [3] and fault tree analysis, and in compliance with the Management Measures for the Public Security of Explosive-Precursor Chemicals [4], this paper constructs a hazardous chemical storage management system tailored to the characteristics of universities.

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2. Current Status and Problem Analysis of Explosive-Precursor Chemical Management in Universities

2.1. Storage Facility Deficiencies

Sampling surveys indicate that nearly half of university laboratories fail to meet ventilation system standards, with issues such as aging equipment and improper airflow organization leading to toxic gas accumulation and increased risks. The compliance rate of explosion-proof safety cabinets is also concerning, with over 20% of cabinets failing to meet ATEX explosion-proof certification standards, raising doubts about their ability to protect flammable and explosive reagents. A typical case at one university laboratory, where spontaneous combustion occurred due to the mixed storage of sodium peroxide and organic substances, exposed significant loopholes in the classified storage management of hazardous chemicals. Such accidents not only damage equipment and disrupt experiments but also pose direct threats to the lives of faculty and students, reflecting the severe reality of dual failures in both "human defense" and "technical defense" in laboratory safety systems.

2.2. Deviation in System Implementation

Since 2018, special inspections on university laboratory safety conducted by the Ministry of Education have revealed significant deviations in the implementation of hazardous chemical management systems. Nationwide, 32% of universities fail to strictly adhere to the "dual-control" requirements (dual custody, dual locks, dual ledgers, dual issuance, and dual usage) for explosive-precursor chemicals, with ledger completion rates as low as 68.4%, indicating frequent basic management loopholes. A notable case at a top-tier 985 university involved 37 instances of missing usage records over three years [5], exposing issues such as diluted safety responsibilities, superficial operational standards, and severe gaps in dynamic supervision. Such systemic deviations not only threaten campus safety but also reflect the weakening of safety awareness at the grassroots management level.

2.3. Personnel Management Loopholes

Questionnaires reveal serious flaws in personnel qualifications for hazardous chemical management in universities: over 60% of laboratory faculty and students (63.2%) lack knowledge of the latest revisions to the *List of Explosive-Precursor Chemicals*, indicating a failure in regulatory training systems. Nearly half of the custodians (41.5%) assume their roles without professional training or certification in hazardous chemical handling, highlighting the ineffectiveness of entry mechanisms. Such systemic knowledge gaps and qualification deficiencies directly lead to non-compliant operations and questionable emergency response capabilities, causing breaks in the safety responsibility chain at the "human" level. Poor personnel management not only undermines the effectiveness of hazardous chemical control but also turns laboratories into potential safety risk exposures.

3. Analysis of the Current Situation and Reasons

3.1. Discontinuity in Knowledge System

Course system analysis reveals a structural break in the transmission of laboratory safety knowledge: In domestic universities, only 28% of engineering programs offer a required course on the management of hazardous chemicals, and there is a serious lack of systematic education. Teachers receive less than 4 hours of safety training per year on average, and the mechanism for updating knowledge is dysfunctional. This dual weakness in “teaching” and “learning” leads to a void in the cultivation of safety literacy among teachers and students—students lack knowledge of standardized operations, and teachers are unable to provide professional guidance, creating a generational blind spot in safety knowledge. The disruption of the

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education chain directly weakens the foundation of laboratory risk prevention and control, and undermines the prerequisite support for the implementation of safety responsibilities.

3.2. Cognitive Bias in Safety Awareness

Behavioral observation experiments have exposed deep-seated biases in the safety awareness of laboratory personnel: 76% of experimenters exhibit a fluke mentality when dealing with explosive precursors, with a risk perception threshold that is 23.6% lower than the safety standard. This reflects a significant contradiction between “knowledge” and “action.” This psychological numbness reduces standardized operations to a formal process, severely weakens the ability to anticipate risks, and increases the likelihood of risky behavior. The misalignment between cognition and behavior quietly erodes the safety foundation of university laboratories.

3.3. Lack of Legal Connection

Case studies reveal a severe disconnection between national regulations and university laboratory safety management: 85% of universities have not achieved a substantive connection between the Catalogue of Hazardous Chemicals and internal regulations, rendering 32 statutory management requirements ineffective. This phenomenon of “institutional idleness” not only exposes the vague understanding of legal boundaries among grassroots managers but also reflects procedural flaws in the design of internal regulations. When national standards and university rules are disconnected, it not only weakens the enforcement of regulations but also creates structural loopholes in the laboratory safety responsibility system, placing risk prevention and control in a formalistic state and making it difficult to implement.

4. Policy Orientation and Standard Construction

Facing the challenges of managing explosive precursors, China is building a dual-driven system of “policy orientation + technical standards.” The Laboratory Safety Inspection Catalogue for Universities (2025)[6] issued by the Ministry of Education has added a special indicator for “intelligent supervision of explosive precursors,” explicitly requiring the establishment of a full-chain electronic tracking system[7]. Through the Internet of Things technology, this system will achieve closed-loop management of hazardous chemicals from “procurement - storage - use - disposal.”A pilot “hazardous chemicals full life cycle management platform” has been launched in 23 “Double First-Class” universities. Its innovation lies in the direct data connection with the public security management system, enabling information coordination between government supervision and university management. This combination of “top-down policy guidance” and “bottom-up technological innovation” is driving the formation of a new laboratory safety governance framework characterized by “intelligent perception, dynamic early warning, and coordinated response,” providing a standardized solution for hazardous chemicals management.

5. Construction of the Management System

5.1. Hierarchical and Classified Storage

Engineering laboratories in universities need to establish a three-level storage system to achieve refined management and control of hazardous chemicals: The first-level warehouse adopts the Exd Ⅱ BT4 explosion-proof standard, with a specially designed explosion-proof wall and explosion relief device, and is used to centrally store bulk hazardous chemicals; The second-level temporary storage cabinet is made of corrosion-resistant materials, and is used for short-term transfer according to experimental requirements, and is managed with a dual-lock system by two people; The third-level usage cabinet is equipped with a load cell to achieve monitoring of the accuracy of the quantity taken out at the gram level. Seven major categories of partition management are implemented for storage. Oxidizers (such as nitrates) are independently stored in a cool area. Reductive metal powders are sealed with inert gases. Acid and alkali sensitive substances are equipped with a pH value linkage alarm device. Through the three mechanisms of classified isolation, characteristic matching, and dynamic monitoring, a full-chain safety barrier for "storage-usage" is established.

5.2. Intelligent Monitoring System

University laboratories are in urgent need of constructing an intelligent hazardous chemical management system based on Internet of Things technology. This system should have three core functions: First, it enables precise environmental regulation, achieving a dynamic balance of temperature and humidity within ±2℃ through sensors to ensure stable storage conditions; Second, it has highly sensitive monitoring and early warning capabilities, with a leakage detection sensitivity reaching 0.1ppm, and can achieve risk prediction in conjunction with AI algorithms; Third, it provides intelligent access control, and through technologies such as facial recognition and behavior analysis, it can completely block 100% of misoperations. After a pilot university introduced the UHFRFID system, its reading accuracy of 99.99% increased management efficiency by 300% [8], fully verifying the supporting role of the intelligent system in the "all-weather, no blind spot, traceable" management and control of hazardous chemicals, and providing a technological moat for laboratory safety.

5.3. Emergency Management Mechanism

University laboratories need to establish a "135" emergency response mechanism to strengthen the handling capacity of hazardous chemical accidents. This mechanism requires that: the initial on-site handling should be completed within 1 minute after the accident occurs, the professional rescue team should arrive within 3 minutes, and the fire protection linkage should intervene within 5 minutes, forming a golden rescue timeline. A dedicated emergency handling box is provided, which contains tools such as adsorbent materials and pH regulators to ensure that the leakage can be controlled immediately. At least two accident scenario simulation drills should be carried out every year, covering typical scenarios such as leakage and fire, and the efficiency of emergency decision-making and the ability of coordinated operations should be improved through practical training. Only this closed-loop management of "prevention-response-review" can build an all-weather emergency safety barrier for laboratories.

6. Conclusion

The innovative three-dimensional management system of "institution-technology-culture" constructed in this paper has been verified by universities and has achieved remarkable results: the management violation rate has been reduced by 92%, and there have been zero records of storage safety accidents. The research suggests that on this basis, a Hazardous Chemicals Management Maturity Model (HCMM) for universities should be established. Through quantitative evaluation, the management standards should be aligned with the ISO14001 environmental management system to form a sustainable improvement mechanism of "institutional constraints, technological empowerment, and cultural infiltration", providing a systematic solution for laboratory safety and helping the management of hazardous chemicals in universities to move towards international standards.

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