Construction and Practice of Safety Governance System for Engineering Laboratories Based on the"Three-Tier Four-Dimension"Closed-Loop Inspection Model

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Abstract. Engineering laboratories serve as vital venues for practical engineering education and scientific research innovation in universities. However, safety hazards in these settings are often highly concealed and difficult to detect in advance, characterized by the intersection of multiple risks. Currently, laboratory safety inspections face three prominent issues: the disconnection between inspection and rectification, a lack of targeted control standards, and insufficient support from information technologies. Integrating the theories of hierarchical risk control and grid-based governance, this study constructs a laboratory safety governance system based on the "Three-Tier Four-Dimension" model. Grounded in micro-grid responsibility management and supported by a lightweight information platform, this system organically integrates three progressive tiers—risk identification, classified governance, and comprehensive supervision—with differentiated control measures for four types of laboratories: electrical, mechanical, telecommunications, and computer rooms. This forms a complete governance closed loop of "discovery–governance–supervision–verification. "Using the Engineering Experimental Center of Guangzhou College of Technology as an empirical sample, the practical application demonstrates that after implementing the system, the hazard rectification completion rate increased from 58.9%to 95.5%, the average rectification cycle was reduced from 8.6 days to 3.2 days, and the recurrence rate of similar hazards decreased from 62.7%to 34.7%. Furthermore, the comprehensive pass rates for specialized inspections across all four types of laboratories exceeded 95%. The "Three-Tier Four-Dimension" model provides a practical reference for the safety governance of multi-type mixed engineering laboratories.

Keywords: Laboratory safety; Safety inspection system; Three-Tier Four-Dimension; Closed-loop management; Differentiated governance; Grid-based governance.

1 Introduction

Engineering laboratories in universities serve as the core platforms for practical teaching and scientific research, and their safe and stable operation is directly related to the quality of talent cultivation, the effectiveness of scientific and technological inno-

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vation, and campus safety[1]. Establishing a long-term mechanism for laboratory safety inspections and hazard rectification, and realizing the dual prevention of hierarchical risk control and hidden danger investigation and treatment, have become the core tasks of laboratory safety management in universities [2].

In recent years, domestic universities have explored various models for the construction of laboratory safety inspection systems. South China University of Technology(SCUT)has built a "1+2+3" laboratory safety management system, positioning safety inspections and safety education as two parallel core pillars[3]. Shenzhen University has focused on the digitalization of laboratory safety patrols, integrating patrol records, hazard reporting, and rectification feedback into an online platform for unified management[4]. East China University of Science and Technology(ECUST)proposed a"Six-in-One"management system, incorporating "inspection and rectification" as an independent component within its overall framework [5]. Based on the PDCA cycle concept, Beijing University of Technology has constructed a closed-loop management process for safety inspections. [6]. Furthermore, Fang Yongzhi et al [7]. proposed a"Four Inspections and One Supervision"inspection system. Grounded in micro-grid management and supported by an information platform, this system organically integrates self-inspections, mutual inspections, specialized inspections, comprehensive inspections, and safety supervision, preliminarily achieving closed-loop management of safety inspections. The aforementioned studies provide important references for the systematization and standardization of laboratory safety inspection work.

However, existing practices still exhibit significant gaps in the following aspects. First, most inspection systems adopt a"parallel"design, listing methods such as self-inspections, specialized inspections, and comprehensive inspections side by side. There is a lack of progressive logic among these inspection types[8], and the transformation from hazard discovery to rectification relies on manual coordination rather than institutional design. Second, inspection standards generally adopt a "one-size-fits-all" approach, failing to formulate differentiated plans based on the risk characteristics of different types of laboratories. This deficiency is particularly prominent in comprehensive engineering experimental centers that encompass multiple types of laboratories, including electrical, mechanical, telecommunications, and computer rooms. Third, current research mostly focuses on enriching inspection methods and increasing inspection frequency, yet it still lacks systematic institutional design and theoretical interpretation regarding the core issue of"how to ensure the implementation of rectifications after inspections".

To address these gaps, this study integrates the theories of hierarchical risk control and grid-based governance to construct a"Three-Tier Four-Dimension"closed-loop inspection model. Taking 42 laboratories at the Engineering Experimental Center of Guangzhou College of Technology as an empirical sample, this study verifies the effectiveness of the model, aiming to provide a systematic framework that is theoretically deducible and practically replicable for the safety governance of multi-type mixed engineering laboratories.

2 Current Status and Problenm Analysis of Laboratory Safety Inspections

2.1 Risk Characteristics of Laboratories

Taking 42 laboratories at the Engineering Experimental Center of Guangzhou College of Technology as an example, they are categorized into four types based on their functions and risk characteristics:electrical laboratories(including Motor Control Laboratory, Power Electronics Laboratory, Electrical and Electronic Laboratory, Electrical Skills Laboratory, Advanced Electrician Training Room, PLC Laboratory, and Circuit Laboratory, with core risks being high-voltage electric shock, short-circuit fires, and poor grounding); mechanical laboratories(including Advanced Manufacturing Training Room, Metalworking Training Room, Hydraulics and Pneumatics Laboratory, Metallography and Heat Treatment Laboratory, Robotics Laboratory, and UAV Laboratory, with core risks being entanglement by rotating parts, lack of protective guards, and pipeline leakage); telecommunications laboratories(including High-Frequency Electronics Laboratory, Communication Principles Laboratory, PTN Optical Transmission Laboratory, Data Communications Laboratory, and FPGA/DSP Laboratory, with core risks being high-frequency radiation, cluttered cabling, and electrostatic breakdown); and computer room laboratories(including AI Computing Power Laboratory, Big Data Development Laboratory, Intelligent Computing Laboratory, and AI Deep Learning Laboratory, with core risks being equipment overheating, power overloading, and poor heat dissipation). The four types of laboratories exhibit significant differences in equipment types, operational specifications, and risk characteristics, which dictates that safety inspection plans must adopt"differentiated strategies based on specific categories"rather than a"one-size-fits-all"approach.

2.2 Distribution Characteristics of Hazard Data

This study retrieved safety inspection records from the university's experimental center spanning 21 months from September 2024 to June 2026. After screening, 198 valid hazard records were obtained. The data originated from daily patrols by laboratory administrators, specialized inspections by college safety officers, and comprehensive inspections by functional departments of the university, covering four types of laboratories: electrical, mechanical, telecommunications, and computer rooms.

The distribution of the 198 valid hazard records in the experimental center is shown in Figure 1. In terms of frequency ranking, "daisy-chaining power strips/unauthorized electricity use"ranked first with 32 records, followed by"missing or unreset machine tool protective guards"with 24 records, and"loose or missing grounding wires"ranking third with 17 records. These top three categories totaled 73 records, accounting for 36. 9%of all hazards, nearly 40%. Further statistics indicate that the top six categories of hazards (from"daisy-chaining power strips"to"cluttered cabling in weak-current rooms/cabinets") totaled 108 records, representing 54.5%of the total. This distribution characteristic indicates that laboratory safety hazards are not uniformly dispersed across various issues but are highly concentrated in a limited number of critical links,

such as electrical connection standards (daisy-chaining power strips, loose grounding wires) and mechanical protective guard resetting (missing protective guards).

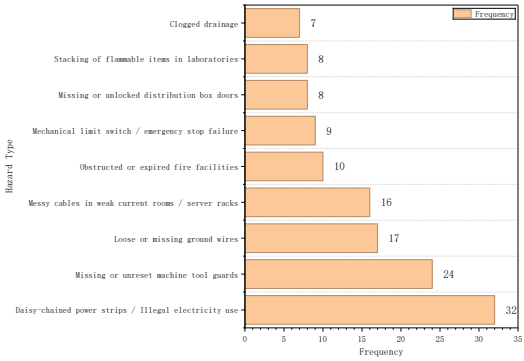


Fig. 1. Frequency Distribution of Laboratory Safety Hazards

To further reveal the correlation strength between hazards and laboratory types, this study constructed a cross-frequency heatmap, as shown in Figure 2. The dark squares on the diagonal indicate that electrical hazards are highly concentrated in electrical laboratories (42 records), mechanical hazards are highly concentrated in mechanical laboratories (36 records), telecommunications hazards are highly concentrated in telecommunications laboratories (16 records), and computer room hazards are highly concentrated in computer room laboratories (12 records). This distribution pattern validates a core judgment: there is a significant"homologous aggregation"characteristic between hazards and laboratory types. In other words, the core risk sources of a specific type of laboratory are determined by its own equipment and operational characteristics. Universal inspection checklists are difficult to accurately cover the specific risk points of various laboratories, which provides direct data support for the subsequent system design of"differentiated strategies based on specific categories. "

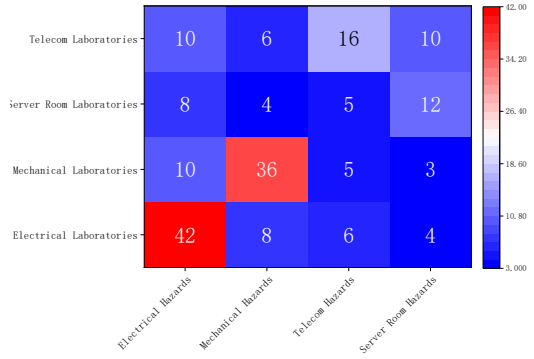


Fig. 2. Cross-frequency heatmap of hazard types and laboratory types

From the perspective of hazard category aggregation, electrical hazards account for 35.4%, ranking first among the four categories; mechanical hazards account for 27.3%; telecommunications hazards account for 16.2%; computer room hazards account for 14.6%; and other hazards account for 6.5%. Electrical and mechanical hazards combined account for 62.7%, making them the twoprimary risk sources in the experimental center. Further analysis of the causes of these hazards reveals that the top three hazards—"daisy-chaining power strips"(32 records), "missing protective guards"(24 records), and"loose grounding wires"(17 records)—all fall under the category of unsafe human behavior. This suggests that safety management should focus on intervening in operational habits and behavioral norms, rather than relying solely on hardware modifications. In addition, 13 other hazards were not included in the heatmap, primarily involving blocked fire protection facilities and obstructed safety passages.

The"homologous aggregation"characteristic of the aforementioned hazard data reveals a deep-seated problem: hazard risks are highly concentrated in specific links of specific types of laboratories. Universal inspection checklists not only fail to accurately cover these differentiated risk points but also lack a mandatory closed-loop design from discovery to rectification. This finding suggests that the laboratory safety inspection system must transition from "parallel listing" to "layered progression, "and from a "one-size-fits-all" approach to"differentiated strategies based on specific categories. "Therefore, this paper constructs a"Three-Tier Four-Dimension"closed-loop inspection model, with its overall architecture and operational logic as follows.

3 Construction of the "Three-Tier Four-Dimension" Closed-Loop Inspection Model

3.1 Connotation and Overall

To address the aforementioned issues, this study integrates the theory of hierarchical risk control with grid-based governance theory to construct a "Three-Tier Four-Dimension" closed-loop inspection model (Fig. 3). Specifically, the hierarchical risk control theory guides the differentiated inspection design of the "Three Tiers" by determining the inspection frequency and precision for different categories of laboratories based on the risk levels of hazard data, thereby achieving a hierarchical allocation of management resources. Meanwhile, the grid-based governance theory guides the design of the micro-grid responsibility system, accurately binding safety responsibilities to specific individuals through a four-tier grid to eliminate buck-passing caused by ambiguous responsibilities. The two theories form a complementary relationship of "hierarchical policy formulation and grid-based implementation": the former addresses resource allocation by determining "what to manage and how strictly to manage," while the latter solves the issue of responsibility transmission by clarifying "who manages and how to hold them accountable." Based on micro-grid responsibility management and supported by an information technology platform, this model upgrades the inspection work from a simple "parallel" superposition to a systematic "progressive" governance.

The "Three Tiers" refer to three progressive levels of safety management. The first tier is the risk identification level, which aims to achieve comprehensive hazard discovery through daily inspections and cross-validation, solving the problem of "whether hazards can be found. " The second tier is the categorized governance level, which aims to implement"one policy for one category"precise interventions targeting the core risks of the four types of laboratories, solving the problem of"whether hazards can be accurately identified. "The third tier is the comprehensive supervision level, which aims to ensure the thorough elimination of hazards through leadership supervision and rectification reviews, solving the problem of "whether hazards can be rectified. "The three tiers form a progressive logic of"identification-governance-supervision. "The output of each tier serves as the input for the next; hazards discovered through self-inspections and mutual inspections enter specialized governance after classification, and unclosed items are automatically escalated to the comprehensive supervision level.

The "Four Dimensions" refer to formulating differentiated inspection standards, grid configurations, and rectification requirements according to the risk characteristics of the four types of laboratories: electrical, mechanical, telecommunications, and computer rooms. This integrates the principle of"differentiated strategies based on specific categories"into the specific operations of each tier. The essence of the"Four Dimensions"framework is to implement the hierarchical risk control theory in the inspection phase by focusing on high-risk items, thereby increasing inspection frequency and precision; meanwhile, low-risk items maintain routine monitoring to achieve the optimal allocation of resources.

It should be noted that this classification is a typical risk dimension division tailored for comprehensive engineering experiment centers. It aims to cover the most core risk types within the sample, rather than serving as an exhaustive classification for all engineering laboratories. For hybrid-function laboratories that encompass multiple types of risks, an adaptive rule of "dominant risk classification + multi-dimensional superimposed inspection" can be adopted. This approach uses the core functions and primary risk sources of the laboratory as the basis for classification, while simultaneously superimposing inspection items corresponding to other secondary risks, thereby avoiding risk omissions caused by a single classification approach.

The operational logic of the model can be summarized as: using the"Three Tiers"to build a progressive governance chain, applying the"Four Dimensions"to implement differentiated control standards, anchoring responsible entities through micro-grids, and achieving full-process recording through information technology. The four elements work synergistically to form a full-chain closed loop of "discovery-governance-supervision-verification".

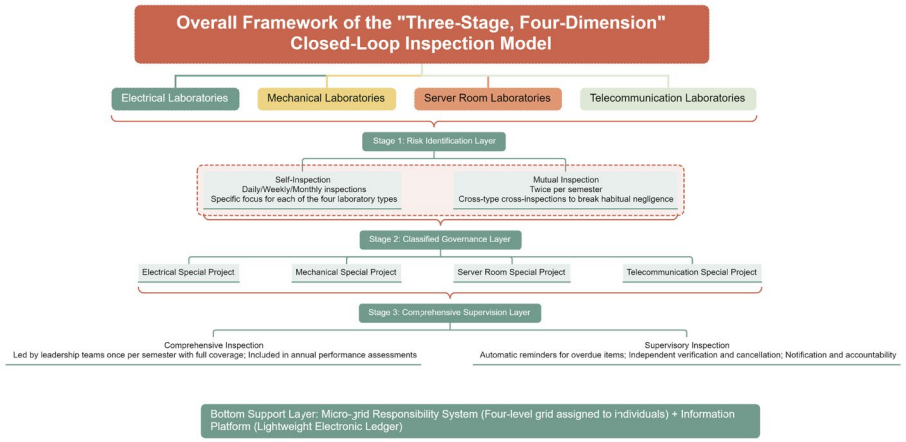


Fig. 3. Overall architecture of the"Three-Tier Four-Dimension"closed-loop inspection model

3.2 Design of the Micro-Grid Responsibility System

The core essence of the grid-based governance theory lies in"dividing management objects into the smallest units and clarifying the responsible entity for each unit. "This study integrates grid-based governance into laboratory safety control to construct a four-tier micro-grid responsibility system, as shown in Table 1. Through the"one person, one grid"responsibility system, safety management responsibilities are directly assigned to specific personnel and laboratories, achieving precise transmission and implementation. The design of each level corresponds to the responsibilities within the"Three-Tier Four-Dimension"model. The Chief Grid Director is responsible for top-level supervision and decision-making; the Dedicated Grid Director is responsible for cross-unit supervision and professional guidance; the Grid Director organizes and implements various inspections within their respective units; and the Grid Member serves as the execution terminal for all inspection requirements and rectification actions.

Table 1. Table captions should be placed above the tables.

Grid Level	Grid Role	Corresponding Personnel	Core Responsibilities
General Grid	Chief Grid Director	Dean/Associate Dean in charge	Organization of comprehensive inspections, supervision of major hazards
Exclusive Grid	Dedicated Grid Director	Safety Officer of the Experiment Center	Special inspections, coordination of mutual inspections, rectification review
General Grid	Grid Director	Laboratory Administrator	Daily self-inspections, hazard reporting, implementation of rectifications
Micro Grid	Grid Member	User Teachers/Students	Compliance with regulations, immediate reporting

3.3 Operational Safeguards for the System

The implementation of the"Three-Tier Four-Dimension"model requires corresponding supporting safeguards. In terms of institutional development, the Detailed Rules for Laboratory Safety Inspections and the Administrative Measures for Closed-Loop Rectification of Hazards were formulated, solidifying the "inspection-feedback-rectification-review" process into a mandatory workflow. Regarding technical support, relying on the laboratory safety management system already deployed by the university, the entire closed-loop management process was covered at zero cost by enabling automatic dispatch of inspection tasks, online hazard registration, full-process tracking of rectifications, and online review and closure. In terms of cultural cultivation, differentiated safety access training was implemented to foster a cultural atmosphere of "everyone values safety, " thereby gaining value recognition for inspection work.

4 Impiementation Effectiveness

The"Three-Tier Four-Dimension"model was officially implemented in the Engineering Experiment Center of Guangzhou Institute of Science and Technology in September 2025. Taking September 2024 to June 2025 as the baseline period(pre-implementation) and September 2025 to June 2026 as the evaluation period(post-implementation), a comparative analysis of the system's operational effectiveness was conducted.

4.1 Effective Implementation of Closed-Loop Management and Significantly Improved Rectification Efficiency

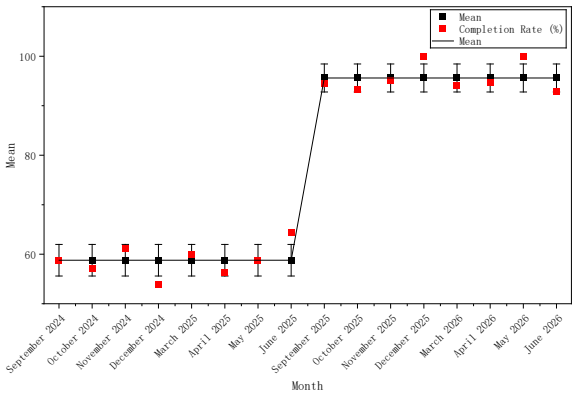


Fig. 4. Trend analysis of rectification completion rate and control limits

After the implementation of the model, the hazard rectification completion rate increased from 58.9%to 95.5%, and the average rectification cycle was shortened from 8.6 days to 3.2 days. The fluctuation range of the completion rate narrowed from

53.8%–64.3%pre-implementation to 92.9%–100%post-implementation. As shown in Figure 4, this indicates that the model not only improves rectification efficiency but also enhances the stability and predictability of the management process.

This study employed a single-group pre-post comparison design without a control group; therefore, it cannot completely rule out the potential impacts of the passage of time, concurrent policy changes, or other external factors on the rectification outcomes. This constitutes a limitation of the current study. Given that the rectification completion rate surged from 58.9% to 94.4% in the first month following model implementation, and the average monthly fluctuation before and after implementation remained within a 10-percentage-point range, future research could further verify the causal effect of the model by introducing a control group or employing an interrupted time series analysis.

4.2 Significant Effectiveness of Differentiated Governance, with Full Compliance Achieved Across All Four Laboratory Types

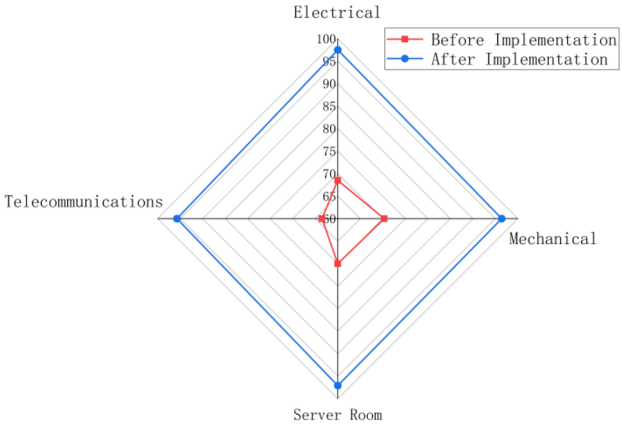


Fig. 5. Radar chart of comprehensive qualification rates for special inspections across four laboratory types

Following the implementation of"one category, one policy"special inspections, the comprehensive qualification rates of all four laboratory types achieved a leapfrog improvement. As shown in Figure 5, from a cross-sectional perspective, the qualification rates of the four laboratory types were uneven before implementation, exhibiting a distinct"depressed"shape; after implementation, all four types exceeded 95%, forming a full and uniform shape. The range narrowed from 6.8 percentage points to 1.4 percentage points, indicating that the differentiated inspection strategy effectively eliminated management disparities among the classified laboratories. From a longitudinal improvement perspective, the telecommunication laboratories showed the largest improvement, primarily attributed to the discovery during the first special inspection that the fiber optic bending radius in multiple laboratories was severely undersized.

After unified cabling rectification, this indicator surged from 50.0%to 95.8%; the computer room laboratories followed, driven by the improvement in cabling organization qualification rates from 60.0%to 96.0%. The comprehensive qualification rates of all four laboratory types increased from 63.5%–70.3%before implementation to 95.7%–97.5%, validating the effectiveness of the"one category, one policy"special inspection in precisely eliminating classification-based management gaps.

4.3 Systematic Transformation of the Management Model

Through the implementation of the model, the safety management of the Experiment Center has achieved fundamental transformations across three levels. First, a shift from"passive response"to"proactive prevention. "The proportion of hazards discovered through self-inspections increased from 38.5%to 59.2%, indicating a significant enhancement in the proactive safety awareness of frontline administrators, teachers, and students, and effectively moving the risk prevention frontier forward. Second, a shift from"single inspection"to "diverse co-governance." "Blind-spot hazards"discovered through mutual and special inspections accounted for 22.4%, verifying that the multi-dimensional inspection network effectively compensates for the coverage insufficiencies of the single model. The integration of the"Four Dimensions"differentiated framework enables various inspections to accurately correspond to the risk characteristics of laboratories, avoiding the low-efficiency"one-size-fits-all"routine patrols. Third, a shift from"paper-based records"to"data-driven management. "The identification of peak hazard periods and the dynamic adjustment of inspections mentioned above are typical examples of data-driven management, marking an upgrade in safety management from"experience-led"to"evidence-based decision-making ".

5 Conclusion

Taking the Engineering Experiment Center of Guangzhou Institute of Science and Technology as an empirical sample, this study integrates the theories of hierarchical risk control and grid-based governance to construct a "Three-Tier Four-Dimension" closed-loop inspection model. The model uses the "Three Tiers" to build a progressive governance chain of"risk identification-categorized governance-comprehensive supervision, " and applies the "Four Dimensions" to implement differentiated control standards for electrical, mechanical, telecommunications, and computer room laboratories. It anchors responsible entities through a micro-grid responsibility system and achieves full-process recording and closed-loop tracking via an information technology platform. Practice has demonstrated that this model effectively resolves prominent issues in traditional inspection systems, such as the disconnection between inspection and rectification, homogenized standards, and hollowed-out responsibilities, significantly improving both hazard rectification efficiency and overall safety management levels.

Certainly, this study still has certain limitations. As a single-university sample, the generalizability of the research conclusions requires further empirical validation

through the practice of more universities. Future promotion should be adaptively adjusted according to the laboratory scale, information technology infrastructure, and management execution conditions of the target institutions. Additionally, with a data cycle of 21 months, the long-term sustainability of the model still needs further tracking and verification. Future research will introduce multi-university comparative analysis and explore historical data modeling methods based on machine learning, aiming to achieve intelligent prediction and dynamic early warning of peak hazard periods, thereby further enhancing the precision and intelligence of laboratory safety governance. Furthermore, attention should be paid to the potential tendency of selective reporting triggered by supervisory pressure during model operation; it is recommended to adopt a non-punitive reporting system to mitigate this issue. Meanwhile, the administrative burden caused by the increased inspection frequency can be alleviated through the hierarchical inspection design.

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References

1. Y. Tao and Y. Feng, “Research on the construction and practice of university laboratory safety management system,” Chemical Enterprise Management, no. 6, pp. 70–73+81, 2026. DOI:10.19900/j.cnki.ISSN1008-4800.2026.06.017.
2. J. Wang, C. Hu, Q. Lin, et al., “Construction of university laboratory safety management system based on dual prevention mechanism,” Experimental Technology and Management, vol. 39, no. 1, pp. 210–213, 2022. DOI:10.16791/j.cnki.sjg.2022.01.042.
3. J. Yan, Z. Liu, X. Song, et al., “Construction of university laboratory safety management system under the traction of safety responsibility system,” Research and Exploration in Laboratory, vol. 43, no. 12, pp. 248–251, 2024.DOI:10.19927/j.cnki.syyt.2024.12.048.
4. J. Liu, Z. Luo, and L. Cai, “Exploration on safety management of university laboratories,” Modern Educational Equipment, no. 3, pp. 56–59, 2024. DOI:10.13492/j.cnki.cmee.2024.03.016.
5. Y. Dong, H. Xu, H. Yuan, et al., “Construction of multi-integrated laboratory safety management system,” Research and Exploration in Laboratory, vol. 43, no. 7, pp. 239–244, 2024. DOI:10.19927/j.cnki.syyt.2024.07.047.

6. M. He, M. Zhao, G. Zhou, et al., "Exploration and practice on the sustainable construction path of university laboratory safety system under PDCA cycle model," Research and Exploration in Laboratory, vol. 43, no. 11, pp. 252–256, 2024. DOI:10.19927/j.cnki.syyt.2024.11.048.
7. Y. Fang, L. Shang, H. Wang, et al., "Construction and practice of the 'four inspections and one supervision' inspection system for university laboratory safety," Experimental Technology and Management, pp. 1–15, 2026.https://link.cnki.net/urlid/11.2034.T.20260610.0955.004.
8. D. Yang, H. Wang, and J. Geng, "Exploration on safety governance of university chemical laboratories from the perspective of three-dimensional risk matrix," Experimental Technology and Management, pp. 1–13, 2026. https://link.cnki.net/urlid/11.2034.t.20260710.1139.002.

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