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# Research on Safety Evaluation Model for Hazardous Chemical Laboratories Based on CMM Entropy Weight Method

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**Abstract** In response to the current problems of different safety management systems, inconsistent inspection standards, and different emphasis on safety facilities in hazardous chemical laboratories in China, a safety evaluation model for hazardous chemical laboratories based on the CMM entropy weight method is proposed in order to improve the safety, reliability, and reduce safety hazards of hazardous chemical laboratories. The entire safety evaluation process is divided into four stages: first, based on the CMM model, establish a maturity model for the safety capabilities of hazardous chemical laboratories from four aspects: personnel, materials, environment, and management systems; Secondly, various evaluation indicators are rated through a questionnaire survey, and the weight of each safety evaluation indicator in the model is determined using the entropy weight method to ensure the objectivity and practicality of each indicator; Once again, calculate the final score of the evaluation object by combining the weights of various survey objects and evaluation indicators; Finally, a safety evaluation was conducted using the Hubei Provincial Chemical Safety Laboratory as the practical object, and based on the evaluation results, targeted rectification suggestions were proposed for the problems existing in the hazardous chemical laboratory, providing decision-making basis for the formulation and improvement of laboratory safety management measures.

**Keywords** CMM; Hazardous Chemicals Laboratory; Safety evaluation; Entropy weight method;

## 1. Introduction

The construction of laboratories is of great significance for cultivating talents and conducting scientific research in universities. In recent years, safety accidents in university laboratories have occurred frequently, and according to statistics, accidents caused by hazardous chemicals account for 80% of laboratory safety accidents.[1] The use of hazardous chemical laboratories in universities is frequent, with strong exploratory research projects and high personnel mobility. Strengthening the safety management of hazardous chemical laboratories has become a consensus among universities in recent years. Therefore, it is necessary to study the safety evaluation model of hazardous chemical laboratories.

In recent years, many scholars have made beneficial explorations in laboratory safety evaluation. Yang Fuqiang et al. established a Petri net model to manage the entire process of hazardous chemicals [2] ; Based on evolutionary game theory, Bai Li et al. established a game model for safety management in university laboratories from the perspective of unsafe behavior of personnel, and studied the influencing factors and dynamic laws of group behavior evolution [3] ; The State Key Laboratory of Mechanical Transmission of Chongqing University developed the laboratory safety management system based on the " DingTalk + Tritium cloud " platform in an agile and collaborative manner, including safety education management, safety inspection management, laboratory site management and experiment reservation management, which improved the technical level of laboratory safety management [4] ; Zhang Liang et al. constructed a dynamic risk assessment model for university laboratory safety based on phase space reconstruction (PSR) and Elman neural network, which accurately identified high-risk levels [5] ; Zeng Jie et al. designed a hazardous chemical management log system for university laboratories based on blockchain technology, ensuring the immutability, transparency, and fairness of hazardous chemical log data in university laboratories [6] ; Jianfeng Yang et al. conducted full lifecycle safety management of hazardous chemicals in universities based on the Internet of Things and artificial intelligence technology [7] .

The Capability Maturity Model (CMM), abbreviated as the Maturity Model [8], originates from the engineering field and is used for process quality management. It has the characteristics of dynamism, process oriented, and the integration of multiple governance entities Chen Qiuxia et al., based on the CMM concept, established a Rural Human Settlements Environment Governance Capability Maturity Evaluation Model (RCMM) from five elements: personnel, organization, technical materials, system, and benefits. Following the "barrel theory", they proposed corresponding optimization strategies for weak key practices [9]; Zhang Hanbo et al. applied maturity models to intellectual property management, providing a guiding framework for the continuous improvement of enterprise intellectual property management capabilities [10]; Based on CMM-SW, Zhang M J divides the maturity level of enterprise knowledge management capabilities into original level, repeatable level, general level, manageable level, and optimization level. Each maturity level reflects the ability to carry out various knowledge management activities in the enterprise [11]; Wang Zhihu et al. constructed a maturity model for safety economic capabilities, providing an improved path for enterprises to expand from single management functions to comprehensive management functions [12]; Yang Dan et al. constructed a maturity model for university research management capabilities, graded the status of university research management capabilities, identified key factors that affect management capabilities, and continuously improved research management capabilities [13].

The above studies are mostly based on qualitative or quantitative aspects, with a few conducting security analysis from the perspective of neural networks. However, such models require a large amount of data support and are difficult to implement. Based on this, this article conducts research on the CMM entropy weight method safety evaluation model. From the aspects of personnel, materials, environment, and management system, a hazardous chemical laboratory safety evaluation model is established based on the Capability Maturity Model (CMM). Through qualitative analysis, different maturity levels are divided to determine the current management capacity and long-term development goals of the laboratory. At the same time, quantitative analysis is used to identify laboratory management loopholes and weak points. Qualitative and quantitative analysis are combined to avoid the nature transformation in the dynamic development process of laboratory management capacity that is only evaluated based on scores in traditional evaluation. This can provide decision-making assistance for university laboratory management. Further utilizing the entropy weight method to improve the subjectivity of weights in the model, ensuring that indicator weights add objective and practical factors on the basis of subjective inference, thereby making the determined weights more realistic and improving the accuracy of model evaluation.

## 2. Establishment of a safety evaluation model for hazardous chemical laboratories

The maturity model of safety management capability in hazardous chemical laboratories is guided by the achievement of strategic goals to ensure the safety management of hazardous chemical laboratories. It measures and evaluates the current situation of safety management capability construction in hazardous chemical laboratories, analyzes the deficiencies and deficiencies in safety management capability of hazardous chemical laboratories, and intuitively understands the maturity level of laboratory safety management capability construction and the weak links in the construction process, and makes targeted improvements.

### 2.1 Capability Maturity Model

The Capability Maturity Model (CMM) divides the evolutionary process of management from disorder to order into several stages, and sorts these stages to form a platform that improves layer by layer, so that the process capabilities of each platform can lay the foundation for reaching the next higher-level platform [14].

CMM gradually introduces change in an incremental manner, clearly defining five different levels of maturity, and an organization can move towards higher levels of maturity through a series of small improvement steps [15]. Therefore, this article divides the maturity level of safety management capabilities in hazardous chemical laboratories into five levels: chaos level, simplicity level, standardization level, optimization level, and lean level, which gradually increase in maturity level [16], as shown in Figure 1.

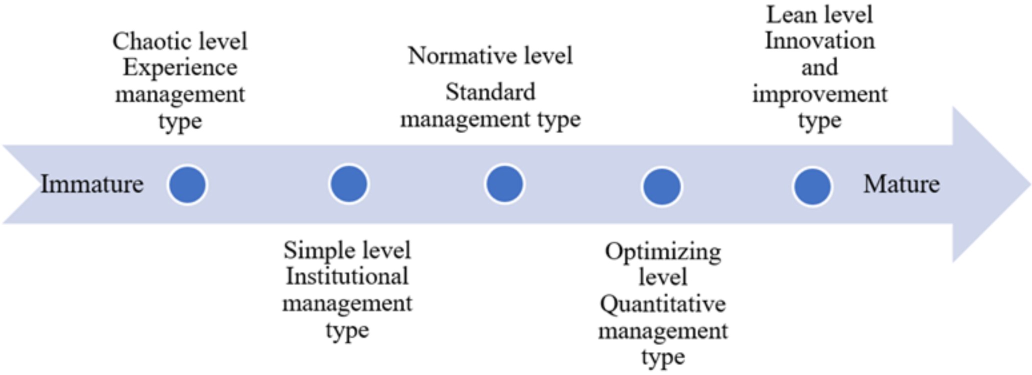


*Figure 1: Maturity level of safety management capability in hazardous chemical laboratory*

1) Chaotic level - experience management type. This stage indicates that the laboratory safety management capability is at the initial level of the maturity model, and the laboratory safety management is in an unordered state. The safety management work of laboratories at this level is carried out based on safety management experience, without clear division of labor among management personnel. Hazardous chemicals and equipment are mainly managed centrally, lacking strict written regulations and a safety assessment system.
2) Simple level - institutional management type. This stage aims to improve the standardization process compared to the previous stage, corresponding to the replicability level in the maturity model. Laboratories at this level have gained a preliminary understanding of safety management and have developed simple management regulations and emergency policies. Schools or colleges have established laboratory safety committees, achieving a repeatable and institutionalized level. However, the regulations and emergency policies formulated are not systematic and scientific enough, and their implementation is insufficient.
3) Normative level - standard management type. After the standardization process improvement at the simple level, laboratory safety management has entered the standardization stage. At this level, the level of laboratory safety management capability is more mature, forming a systematic safety management system. The responsibilities of management personnel are clearly defined, and strict laboratory safety management regulations and safety access systems are formulated. Regular safety management knowledge and skills testing is conducted on relevant personnel entering the laboratory, achieving standardized and procedural safety management of the laboratory.
4) Optimizing level - quantitative management type. After quantitative process improvement at the previous level, the safety management capability level of hazardous chemical laboratories has been upgraded to quantitative management. The safety management of hazardous chemical laboratories at the optimization level has achieved a transformation from qualitative to quantitative management. Quantitative analysis of various safety management activities has been carried out to determine quantitative indicators, making management more targeted. The school or college shall develop corresponding emergency plans for safety accidents in hazardous chemical experiments, and carry out hidden danger investigation plans for various hazardous sources in the laboratory. The management personnel of hazardous chemical laboratories adopt a classified and regional approach to safety management, establish a safety management capability evaluation system, and achieve quantitative management of the laboratory.
5) Lean level - innovative and improved. The level of safety management capability in hazardous chemical laboratories has reached lean level after continuous improvement at the optimizing level. A hazardous chemical laboratory at this level has a mature and comprehensive safety management system, and laboratory management and users have strong safety awareness. The hazardous chemicals and related equipment in the laboratory are managed by dedicated personnel. By researching and

introducing new methods and technologies, we aim to promote the continuous improvement of safety management capabilities in hazardous chemical laboratories.

**2.2 Determination of maturity index evaluation criteria**

The maturity evaluation indicators for the safety capability of hazardous chemical laboratories are determined from the aspects of personnel, materials, environment, and management systems. The safety management evaluation indicator system for hazardous chemical laboratories constructed in this article includes four primary indicators and 17 tertiary indicators, as shown in Table 1, to more comprehensively reflect the safety management issues and requirements of hazardous chemical laboratories [17-21].

**Table 1:** Safety Management Indicator System for Hazardous Chemicals Laboratories

| Primary indicators | Intermediate indicators | Tertiary indicators |
|---|---|---|
| Human factors (A) | Safety Awareness ($A_1$) | Student safety education ($A_{11}$) |
| | | Safety training for management personnel ($A_{12}$) |
| | Pre experimental training ($A_2$) | Training on experimental operation procedures for scientific researchers ($A_{21}$) |
| Material factors (B) | Identification of Risk Material Information ($B_1$) | Accurately identifying the danger of hazardous materials ($B_{11}$) |
| | | Timely release risk material information through various means ($B_{12}$) |
| | Risk material management ($B_2$) | Classification and zoning storage management of risk materials ($B_{21}$) |
| | | Complete records of material access and exit ($B_{22}$) |
| Environmental factors (C) | Material Reserve Environment ($C_1$) | Set up reasonable storage environments based on the characteristics of hazardous chemicals ($C_{11}$) |
| | Experimental Environment ($C_2$) | Separate the experimental area from the risk material reserve area ($C_{21}$) |
| Management factors (D) | Safety management system ($D_1$) | Establish a registration system for the admission of hazardous chemical laboratories ($D_{11}$) |
| | | Establish a safety management training program ($D_{12}$) |
| | | Establish a hierarchical security management system ($D_{13}$) |
| | | Implement on-site "5s" management ($D_{14}$) |
| | | Establish a safety management assessment system and assign a dedicated person to be responsible for it ($D_{15}$) |
| | Contingency management ($D_2$) | Emergency rescue facilities and equipment are sound, such as ventilation and sprinkler facilities, fire extinguishers, gas masks, etc ($D_{21}$) |
| | | There are specialized emergency rescue personnel ($D_{22}$) |
| | | Regularly conduct emergency drills for sudden accidents in hazardous chemical laboratories ($D_{23}$) |

**2.3 Safety evaluation method for hazardous chemical laboratory based on CMM**

1) Design a survey questionnaire. The survey indicators correspond to the 17 three-level indicators mentioned above in sequence, and the questionnaire recipients rate the effectiveness of the safety management process in hazardous chemical laboratories. The maximum score is 10 points. A score of 3 points or below is considered chaotic, simple level is 3-6 points, normative level is 6-7.5 points, optimizing level is 7.5-9 points, and lean level is 9-10 points.

2) Calculate weights and indicator scores. The questionnaire survey is conducted anonymously, and the respondents only reflect their own identities. The questionnaire is distributed to safety management personnel, full-time teachers, and research personnel and students who will enter the laboratory. The scoring weights for these three types of personnel are 0.5, 0.3, and 0.2, respectively. After calculating the average score of each type of personnel for a certain indicator, the weighted sum method is used to calculate the comprehensive score of the indicator.
3) Determine maturity level. Calculate the total score of the laboratory based on the weight of various indicators, determine the maturity level of the laboratory's safety management ability, and ensure that the laboratory's level meets the evaluation results of all three level indicators at this level, which are at or above the normative level.
4) Develop management optimization strategies. Based on the calculated scores and weights of each indicator, it can only be visually seen that the hazardous chemical laboratory has weak links in safety management. Targeted improvements and enhancements should be made to indicators that have not reached the standard level to achieve the goal of improving the maturity level of safety management capabilities.

## 3. Determination of Index Weights for Evaluation System

After receiving feedback from the survey questionnaire on the scores of each indicator, the entropy weight method is used to determine the entropy weight values of each three-level evaluation indicator, in order to obtain a relatively objective comprehensive evaluation score for the maturity level of safety management capabilities in hazardous chemical laboratories [22-25].

**Data standardization**

Firstly, perform dimensionality reduction and quantification processing on various indicators. According to the scoring principles of the survey questionnaire designed in this article, if all indicators are scored as positive indicators, then:

$$y_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \tag{1}$$

**Calculate the ratio of each indicator under each scheme**

$$P_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}} \tag{2}$$

**Calculate the information entropy of each indicator**

$$e_i = -\frac{1}{\ln m}\sum_{i=1}^{m} p_{ij} \ln p_{ij} \tag{3}$$

Where, $e_{ij}$ is the entropy value of the $i$ -th index; $1/\ln m$ is the information entropy coefficient.

**Calculate the entropy weight of each indicator**

$$w_i = \frac{1-e_i}{n-\sum_{i=1}^{n} e_i} \tag{4}$$

Based on the final weights obtained, calculate the comprehensive scores of various personnel on the maturity level of safety management capabilities in hazardous chemical laboratories. Then, based on the weighting of three types of personnel, calculate the final score of the maturity level of safety management capabilities in hazardous chemical laboratories.

## 4. Application of safety evaluation model for hazardous chemical laboratory

### 4.1 Overview of Hazardous Chemicals Laboratory

The Hubei Provincial Chemical Safety Laboratory is jointly established by the Hubei Provincial Emergency Management Department and Wuhan Institute of Technology. With the support of the laboratory, the Hubei Provincial Chemical Safety Testing Center is established to undertake chemical safety risk testing throughout the province, provide technical support for chemical safety supervision, and provide testing reports for emergency rescue and investigation of chemical accidents throughout the province.

The laboratory currently has 132 sets of large and medium-sized testing equipment, including 3 sets of portable gas chromatography-mass spectrometry, portable infrared spectrometer, and other emergency rescue on-site rapid testing and analysis equipment; 25 sets of chemical physical hazard identification equipment, including water release tester, metal corrosion tester, self heating substance/thermal stability tester, etc; 26 sets of physical and chemical property testing equipment, including oxygen bomb calorimeters, closed flash point testers, and microcomputer melting point testers; And 68 sets of on-site detection equipment, including laser rangefinders, infrared thermometers, night vision devices, and accident scene detection boxes, some of which are shown in Figure 2.


(a) (b)

(c) (d)

*Figure 2: Experimental Equipment for Hazardous Chemicals Laboratory*

The laboratory has the ability to identify the physical hazards of chemicals, test the physical and chemical properties of chemicals, and perform rapid analysis of chemicals in three categories and 20 subcategories. Covering the main content of chemical safety production supervision and emergency rescue on-site analysis.

The laboratory's various appraisal rooms and office areas are reasonably partitioned, and there are dedicated archive rooms and storage rooms, with a scientific layout.

**4.2 Questionnaire survey**

Design a survey questionnaire based on the maturity evaluation criteria for safety management capabilities in hazardous chemical laboratories mentioned above, and score 17 third level indicators separately. The questionnaire is distributed to three types of personnel, namely laboratory safety management personnel, full-time teachers, and students and researchers who will enter the laboratory. The evaluations of these three types of personnel represent the understanding of the maturity level of safety management capabilities in hazardous chemical laboratories by personnel involved in management, teaching, and practice. Selecting these three types of personnel for investigation can make the investigation results more objective and accurate.

600 survey questionnaires were distributed, and 557 valid feedback were received, with a response rate of 93%.

**4.3 Data organization**

Calculate the average score of each indicator for three types of personnel, and then calculate the comprehensive score of each indicator based on the personnel weight ratio mentioned above. The results are shown in Table 2.

**Table 2:** Indicator Score Table

| Index | Score | | | Weighted Score |
|---|---|---|---|---|
| | Administrators | Full-time teachers | Students and Researchers | |
| $A_{11}$ | 7.82 | 9.08 | 8.96 | 8.426 |
| $A_{12}$ | 7.30 | 7.88 | 8.48 | 7.710 |
| $A_{21}$ | 8.64 | 8.48 | 7.96 | 8.456 |
| $B_{11}$ | 8.16 | 8.48 | 7.06 | 8.036 |
| $B_{12}$ | 8.98 | 7.72 | 7.74 | 8.354 |
| $B_{21}$ | 8.72 | 8.52 | 6.58 | 8.232 |
| $B_{22}$ | 7.84 | 8.86 | 7.26 | 8.030 |
| $C_{11}$ | 7.48 | 7.12 | 6.86 | 7.248 |
| $C_{21}$ | 8.46 | 8.08 | 7.42 | 8.138 |
| $D_{11}$ | 7.14 | 8.90 | 6.14 | 7.468 |
| $D_{12}$ | 8.32 | 6.88 | 8.22 | 7.868 |
| $D_{13}$ | 7.12 | 8.24 | 7.72 | 7.576 |
| $D_{14}$ | 8.74 | 8.38 | 7.80 | 8.444 |
| $D_{15}$ | 8.06 | 7.84 | 8.68 | 8.118 |
| $D_{21}$ | 8.38 | 8.14 | 6.44 | 7.920 |
| $D_{22}$ | 7.64 | 8.70 | 8.70 | 8.170 |
| $D_{23}$ | 8.96 | 8.68 | 7.42 | 8.568 |

**4.4 Determination of indicator weights**

Use the entropy weight method to obtain the weights of 17 tertiary indicators, as shown in Table 3.

**Table 3:** Indicator Weight Table

| Index | Weighted Score | Weight |
|---|---|---|
| $A_{11}$ | 8.426 | 0.04967 |
| $A_{12}$ | 7.710 | 0.05675 |
| $A_{21}$ | 8.456 | 0.05061 |
| $B_{11}$ | 8.036 | 0.05050 |
| $B_{12}$ | 8.354 | 0.12434 |
| $B_{21}$ | 8.232 | 0.04967 |
| $B_{22}$ | 8.030 | 0.06342 |
| $C_{11}$ | 7.248 | 0.06004 |
| $C_{21}$ | 8.138 | 0.05259 |
| $D_{11}$ | 7.468 | 0.06343 |
| $D_{12}$ | 7.868 | 0.04960 |
| $D_{13}$ | 7.576 | 0.05518 |
| $D_{14}$ | 8.444 | 0.05297 |
| $D_{15}$ | 8.118 | 0.07180 |
| $D_{21}$ | 7.920 | 0.04979 |
| $D_{22}$ | 8.170 | 0.04952 |
| $D_{23}$ | 8.568 | 0.05013 |

After determining the weights of each indicator, combined with the weighted scores of the three types of survey objects, the final score of the maturity level of the safety management capability of the hazardous chemical laboratory is obtained, as shown in Table 4.

**Table 4:** Final Score of Questionnaire Survey

| Respondents | Score | Final Score |
|---|---|---|
| Administrators | 8.1377 | |
| Full-time teachers | 8.1914 | 8.0504 |
| Students and Researchers | 7.6203 | |

**4.5 Evaluation Results and Improvement Strategies**

A comprehensive evaluation of the maturity level of safety management capabilities in hazardous chemical laboratories was conducted using CMM and entropy weight method. The laboratory scored 8.0504, which is within the range of "optimizing level" scores. The scores of all three levels of indicators are at or above the

"normative level", indicating that the overall construction of safety management capabilities in the laboratory is good and basically mature. At the same time, the feasibility of the evaluation model is also well verified.
Based on the comprehensive scores and weight sizes of each indicator in Table 3, create a scatter plot of the importance of each indicator, as shown in Figure 3, to determine the priority of indicator rectification. In the figure, the weights on the vertical axis increase sequentially, and the maturity score on the horizontal axis increases accordingly. Therefore, the upper left area belongs to indicators with significant weight but low scores, and should be prioritized for rectification; Next is to rectify the indicators in the lower left area, which have low weights but also low maturity scores; The lower right area belongs to indicators with low weights and high scores. You don't need to pay attention to these indicators for now, maintain the status quo, and invest more energy in other areas with higher importance; For indicators with high weights and scores in the upper right region, new technologies and methods

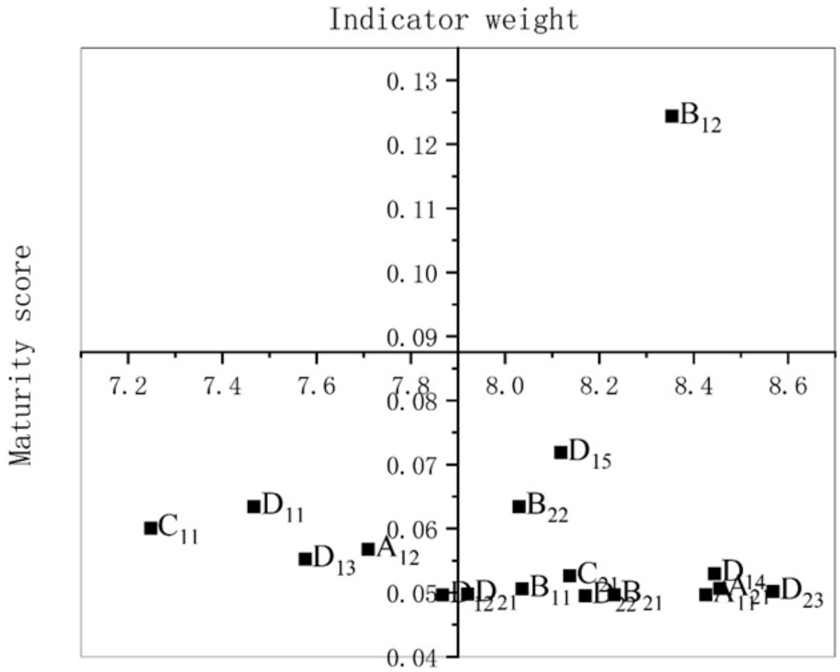


*Figure 3: Scatter plot of indicator importance*

The $B_{12}$ index with the highest weight in the laboratory has a score in the "optimization level" range, and only needs to maintain the status quo and improve; The scores of $C_{11}$ and $D_{11}$ indicators are only within the "normative level" range and should be prioritized for improvement.

**5 Conclusion**

1) The selection of evaluation indicators for the safety evaluation model of hazardous chemical laboratories based on the CMM entropy weight method meets the basic requirements of safety management in hazardous chemical laboratories. This model combines qualitative and quantitative analysis to objectively and accurately evaluate the maturity level of safety management capabilities in hazardous chemical laboratories. Evaluating the maturity level of laboratory safety management capability is only a means, and the true purpose is to use the comprehensive evaluation results to improve safety management work. By combining the evaluation model with the scoring of various evaluation indicators and the obtained weights, identify the weak links in laboratory safety management, and develop reasonable improvement plans.
2) In the evaluation of the maturity level of safety management capabilities in a hazardous chemical laboratory of a certain university, the most familiar safety management personnel, full-time teachers, and students and researchers who will enter the laboratory are selected to rate the current status of

laboratory safety management, covering three stages of management, teaching, and practice, making the evaluation results more objective.

3) The entropy weight method is used to objectively and scientifically assign weights to the safety management evaluation indicators of hazardous chemical experiments, in order to determine the priority of rectification for each evaluation indicator. Based on the weight and score of each indicator, the indicators with high weight and low score are selected for priority rectification.

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