Developing Indicator Systems for Evaluating Biosafety in BSL-2 Laboratories

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Abstract. The management of laboratory biosafety is facing vital difficulties around the world, especially for a large number of biosafety level 2 (BSL-2) laboratories. The purpose of this paper is to propose two indicator systems for both a single laboratory and the unit level (the whole company, school, department, hospital, or organization). Based on the comprehensive indicator systems, 14 experts were asked to rate the indicators. The Analytic Hierarchy Process (AHP) was used to obtain the weights of the indicators. The indicator systems can help the laboratory staff in BSL-2 laboratories to control and reduce biological risks. Moreover, it can contribute to the management of laboratory biosafety for administrators and government departments.

Keywords: indicator system, laboratory biosafety, BSL-2, AHP, weights

1 Introduction

Laboratory biosafety is a critical strategic national reserve and a vital resource for the prevention and management of new and emerging infectious illnesses[1]. However, events such as the anthrax mailings in the United States in 2001, severe acute respiratory syndrome coronavirus 1 (SARS-CoV-1) in 2003, the COVID-19 pandemic that was caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and monkeypox virus in 2022 raises awareness of laboratory biosafety around the world [2-4]. Moreover, with the rapid development in the field of biotechnology, it has increased the risk of misuse and abuse [5,6]. Therefore, laboratory biosafety has become a focus point and a popular topic in academia due to its importance and the enormous threats posed by unexpected events.

Nowadays, global regulatory organizations have scattered indicators for laboratory biosafety management, and the evaluation method is largely subjective and artificial. In order to evaluate the management of laboratory biosafety, this paper aims to establish a scientific, comprehensive indicator system and calculate the weights of the indicators using AHP. Two levels, the laboratory level and the company, school, department, hospital, or organizational unit level, are designed, respectively.

S. Yacob et al. (eds.), *Proceedings of the 2023 7th International Seminar on Education, Management and Social Sciences (ISEMSS 2023)*, Advances in Social Science, Education and Humanities Research 779,
https://doi.org/10.2991/978-2-38476-126-5_117

2 Research methodology

In order to build the indicator system for evaluating the development of laboratory biosafety, the following two procedures were carried out:

2.1 Identifying the indicator system of the laboratory and the unit

In the year 2022, we published a specification for the evaluation of biosafety laboratory management based on the nine published standards: Water Pollutant Discharge Standards for Medical Institutions (GB 18466)[7]; General Requirements for Laboratory Biosafety (GB 19489)[8]; Mobile Laboratories Biosafety Requirements (GB 27421)[9]; Technical Specifications for Biosafety Laboratory Construction (GB 50346)[10]; General Guidelines for Biosafety in Pathogenic Microbiology Laboratories (WS 233); Biosafety Labeling for Pathogenic Microbiology Laboratories (WS 589); Measures for the prevention and control of environmental pollution by waste hazardous chemicals (State Environmental Protection Administration Order No. 27); Technical Rules for the Safe Transport of Dangerous Goods by Air (Civil Aviation Administration of China Order No. 216) and List of human-transmissible pathogenic microorganisms (Wei Textbook Development [2006] No. 15). It was one of the Zhejiang Provincial Local Standards. The primary indicators include organization management, laboratory facilities and equipment, personnel management, bacterial (viral) species and biological samples management, laboratory waste management, laboratory internal affairs management and material identification, fire management security and confidentiality management, and others, were proposed in this local standard.

In summary, for the laboratory level, 7 primary indicators, 16 secondary indicators, and 25 tertiary indicators were identified. For the hospital or other unit level, 7 primary indicators, 18 secondary indicators, and 27 tertiary indicators were constructed. The detailed indicators can be found in Tables 2 and 3.

2.2 Using AHP to determine the indicator weights of the laboratory and the unit

14 experts, with a mean age of 51.07 and a standard deviation of 7.28, make up our expert panel. The research areas of these experts are related to laboratory biosafety, with six experts in the field of clinical testing, five in laboratory biosafety and quality management, two in public health and one in epidemiology. At the same time, 10 of them are men and 4 are women.

The experts were asked to give the relative magnitude rankings independently based on Saaty's AHP table [11]. Then we average the feedback value and construct the pairwise comparison matrix. Yaahp version 12.10 was used to construct the AHP model, pairwise comparison matrices and to perform consistency checks. Four levels exist in the laboratory and the unit evaluation indicator systems, respectively. There are 24 comparison matrices in the laboratory evaluation indicator systems and 26 comparison matrices in the unit evaluation indicator systems. The weights (denotes by W_i) of the indicators at each level are calculated by the formula

$$W_i = \frac{\overline{W_i}}{\sum_{i=1}^{n} \overline{W_i}}.$$

The largest characteristic root of the comparison matrix is calculated by the formula

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{B_i W}{n W_i}$$

where B denotes the comparison matrix and W is the eigenvector.

The formula for calculating the consistency indicator CI is

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

where n is the comparison matrix order. Consistency ratio (CR) test using the average random consistency index RI given by Saaty (detailed in Table 1) and calculated by formula

$$CR = \frac{CI}{RI}$$

CR < 0.1 means that the weights of the indicators were reasonably assigned and the consistency was good.

Table 1. Average Random Consistency Index RI

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

All of our comparison matrices passed the consistency test and then the weights of all the indicators were obtained. We normalize each indicator with formula

$$x' = \frac{x - \min(x)}{\max(x) - \min(x)}$$

with x is the raw data that we obtained. $\min(x)$ and $\max(x)$ are the minimal and maximum value of x. The final weights regarding the indicators were displayed in Tables 2 and 3.

Table 2. Laboratory Evaluation Indicator System and Weights

Primary indicator	Weights	Secondary indicator	Weights	Tertiary indicator	Weights
Organization management	0.2557	Organizational structure and responsibilities	0.3332	Duties of person in charge in laboratory	0.8005
				Duties of laboratory personnel	0.1995

Primary indicator	Weights	Secondary indicator	Weights	Tertiary indicator	Weights
		Management of experimental activities	0.3332	Experimental activities	1
		Personal protection	0.3332	Personal protection	1
Laboratory facilities and equipment	0.0872	Facilities and equipment	0.3337	Ventilation and air conditioning systems	0.3093
				Access control system	0.1993
				Power supply system	0.3574
				Face washing, eye washing and spraying devices	0.134
		Biosafety related equipment	0.6663	Biosafety cabinet	0.5009
				Disinfection and sterilization equipment	0.5009
Personnel management	0.2179	Admission	0.3332	Laboratory personnel admission management	1
		Training	0.3332	Experimental personnel training	1
		Personnel responsibilities	0.3332	Personnel requirements for laboratory waste disposal	1
Bacterial (viral) species and biological samples management	0.2356	Management of use, preservation and destruction	1	Preservation of bacterial (viral) species and biological samples	0.3676
				Destruction of bacterial (viral) species and biological samples	0.2818
				Requirements for preserved facilities and equipment	0.1999
				Bacterial (viral) species and biological samples data archiving	0.1503
	0.0784	Experimental waste	1	Experimental waste packaging	0.25

Primary indicator	Weights	Secondary indicator	Weights	Tertiary indicator	Weights
Laboratory waste management				Disinfection and sterilization of experimental waste	0.75
Laboratory internal affairs management and material identification	0.0619	Laboratory internal affairs management requirements	0.2859	Internal Affairs Management Requirements	1
		Disinfection and Sterilization	0.5719	Disinfection and Sterilization	1
		Identification	0.1422	Biosafety identification	1
Fire management, security and confidentiality management	0.0633	Fire Management	0.3333	Management of high-pressure gas, combustible gas and liquid	1
		Security	0.3333	Laboratory security	1
		Confidentiality management	0.3333	Information security management	1

Table 3. Company/School/Department/Hospital/Organization Unit Evaluation Indicator System and Weights

Primary indicator	Weights	Secondary indicator	Weights	Tertiary indicator	Weights
Organization management	0.3111	Organizational structure and responsibilities	0.18	Corporate capacity	0.2464
				Duties of legal representative	0.2982
				Biosafety committee	0.2464
				Responsibilities of biosafety management department	0.2089
		Management system establishment and relative documents	0.162	Establishment of documents	0.5
				Documents control programs	0.5
		Record management	0.162	Requirements of filing	1
		Risks assessment and control	0.224	Risk assessment	1
		Emergency response	0.1617	Emergency plan	0.668
				Report and disposal of accidents	0.334

Primary indicator	Weights	Secondary indicator	Weights	Tertiary indicator	Weights
		Safety inspection	0.1103	Safety inspection	1
Personnel management	0.1766	Training management	0.7503	Laboratory personnel training	1
		Health management	0.2503	Laboratory personnel health management	1
Bacterial (viral) species and Biological samples management	0.1917	Collection, packaging of bacterial (viral) species and biological Samples	0.3276	Requirements of collection and packaging of Bacterial (viral) species and biological samples	0.5
				Packaging requirements for transportation and handover of bacterial (viral) species and biological samples	0.5
		Transportation management of bacterial (viral) species and biological samples management	0.2598	Application for transportation of bacterial (viral) species and biological samples	0.3353
				Requirements for carriers of bacterial (viral) species and biological samples	0.6667
		Management of use, preservation and destruction	0.4126	Use of bacterial (viral) species and biological samples	0.4994
				Preservation of bacterial (viral) species and biological samples	0.4994
Laboratory waste management	0.1059	Laboratory wastewater discharge	0.3333	Discharge requirements of laboratory wastewater	1
		Experimental waste	0.6667	Experimental waste packaging	0.5
				Storage of experimental waste	0.5
Laboratory internal af-	0.0554	Identification	1	Biosafety identification	1

Primary indicator	Weights	Secondary indicator	Weights	Tertiary indicator	Weights
fairs management and material identification					
Fire management, security and confidentiality management	0.1132	Fire Management	0.333	Management of high-pressure gas, combustible-gas and liquid	1
		Security	0.333	Laboratory security	1
		Confidentiality management	0.333	Information security management	1
Others	0.0461	Safety plan	1	Safety plan requirements	1

3 Conclusions

A large number of biosafety level 2 (BSL-2) laboratories have been built because diagnostic and experimental activities involving "high pathogenicity agents" should be carried out in BSL-2 laboratories or higher level biosafety laboratories[12]. Therefore, it is necessary to improve the overall level of biosafety management. For BSL-2 laboratories in China, a thorough framework of legal and regulatory standards is particularly inadequate[13]. As of May 24, 2023, there were 4905 BSL-2 laboratories and 2860 units that included BSL-2 laboratories in the Zhejiang province, but a lack of management indicator systems remained scarce.

This paper proposes comprehensive indicator systems for both a single laboratory and for units that include many laboratories. For example, a hospital is a unit that has more than one laboratory. Therefore, the indicators may overlap, such as organization management, which exists both in the laboratory and the unit index systems, but they have different secondary or tertiary indicators with different weights.

For the management of laboratories, 7 primary indicators, including organization management, laboratory facilities and equipment, personnel management, bacterial (viral) species and biological samples management, laboratory waste management, laboratory internal affairs management and material identification, and fire management, security and confidentiality management, 16 secondary indicators, and 25 tertiary indicators were constructed. In terms of the weights of primary indicators, organization management, bacterial (viral) species and biological samples management, and personnel management were in the top three with weights greater than 0.2.

For the management of units, 7 primary indicators, including organization management, personnel management, bacterial (viral) species and biological samples management, laboratory waste management, laboratory internal affairs management and mate-

rial identification, fire management, security and confidentiality management, and others, 18 secondary indicators, and 27 tertiary indicators were identified. Organization management ranked first with more than 0.3 weights. Then bacterial (viral) species and biological samples management, and personnel management were in second and third place with weights greater than 0.15.

Some limitations appear in the process of building the indicator systems and need future research. First, all of our experts are from Zhejiang, one province of the 23 provinces, 5 autonomous regions, 4 municipalities, and 2 special administrative regions in China. Second, AHP has the drawback that rankings may vary when we add or subtract experts.

We highly suggest that the indicator systems be used in scenarios such as self-inspection and inspection or supervision by a higher authority. To be specific, self-inspection means that the laboratory or unit can find their own strengths and weaknesses according to the indicators in the indicator systems. Moreover, they can improve themselves by using these specific indicators in their daily routines. Inspection or supervision by a higher authority means that the higher authority can objectively inspect the laboratory or unit by scoring it according to the indicator systems. It will give the higher authorities a comprehensive understanding of the laboratory or unit. Furthermore, the higher authorities can assign a laboratory or unit a rating of excellent, good, or failing based on the scores. Overall, the indicator systems can help laboratories become more capable of controlling biosafety risks and serve as a basis for further refinement of laboratory safety management.

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