Chemical hazard assessment and risk modeling

UDC 629.039.58: 0004.9 DOI: 10.25514/CHS.2021.2.20013

Improving Chemical Laboratory Safety by Analyzing Hazard Identification and Hazard Evaluation

***A. Geetha Bhavani*[1]✉ *and Ramesh Kumar Ganta*[2]**

[1]Department of Chemistry, School of Sciences, Noida International University, Noida, India, e-mail: ageethabhavani@gmail.com
[2]National Disaster Management Authority, NDMA Bhawan, New Delhi, India

Received: June 17, 2021; Revised: August 19, 2021; Accepted: August 24, 2021

Abstract – In research labs, the identification or recognition of risk is necessary to avoid or minimize the risks prior to the start of work related to chemicals utilization. The manual and standard operating procedure is mandatory in every lab with trouble shooting procedures. These procedures effectively evaluate the potential hazard conditions by step wise identification and responding. The collection of laboratory data for implementation of hazard identification and evaluation needs constructive methodologies. The factors that can contribute to the incident, includes the lack of comprehensive guidance on managing the hazards, risk assessments etc. Every academic society should reminisce that the past laboratory incidents are lessons are providing the chance to revise the existed practices and policies.

Keywords: Identification, Evaluation, Hazards, Safety.

Оценка и моделирование риска химической опасности

УДК 629.039.58: 0004.9 DOI: 10.25514/CHS.2021.2.20013

Повышение безопасности в химической лаборатории путем анализа идентификации опасности и оценки опасности

***А. Г. Бхавани*[1]✉, *Р. К. Ганта*[2]**

[1]Факультет химии, Центр инновационных научных исследований, Международный университет Нойды, Нойда, Индия, e-mail: ageethabhavani@gmail.com
[2]Национальное управление по борьбе со стихийными бедствиями, Нью-Дели, Индия

Поступила в редакцию: 17.06.2021 г., после доработки: 19.08.2021 г., принята в печать: 24.08.2021 г.

Аннотация – В исследовательских лабораториях идентификация или признание риска необходимо, чтобы избежать или минимизировать риски до начала работ, связанных с использованием химикатов. Ручная и стандартная рабочая процедура является обязательной в каждой лаборатории, где есть процедуры устранения неисправностей. Эти процедуры эффективно оценивают условия потенциальной опасности путем пошаговой идентификации и реагирования. Сбор лабораторных данных для выполнения идентификации и оценки опасностей требует конструктивных методологий. Факторы, которые могут способствовать инциденту, включают отсутствие исчерпывающих руководств по управлению опасностями,

оценке рисков и т. д. Каждое научное сообщество должно помнить, что прошлые лабораторные инциденты являются уроками, дающими возможность пересмотреть существующие практики и политики.

Ключевые слова: оценка опасности, идентификация, безопасность.

INTRODUCTION

The proposed hierarchy of measures the events to eliminate or reduce the level of occupational risks is shown in Figure 1.

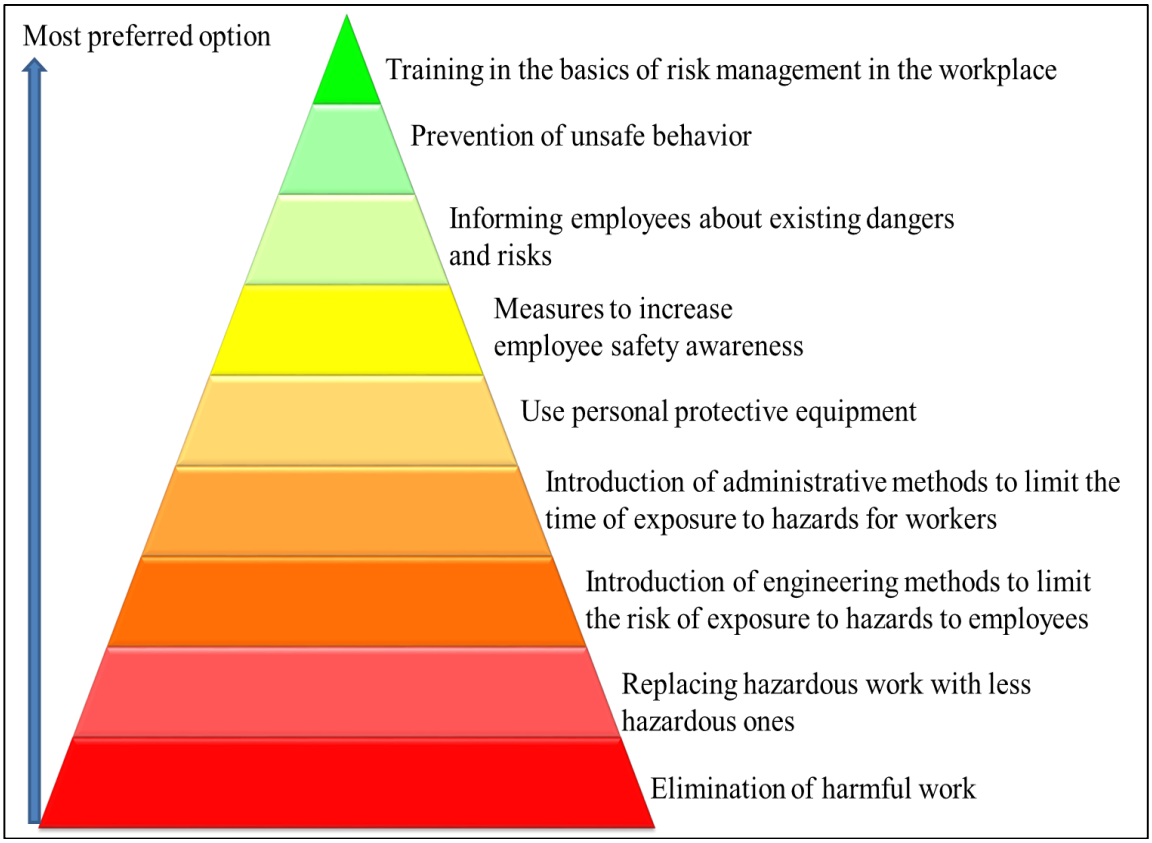


Fig. 1. Hierarchy of measures to eliminate or reduce the level of professional risks.

For every potential research and academic laboratory clearly follow the safety guidelines and protocols to follow as part of safety ethos [1]. The organizations assimilate the best hazards safety methodologies to classify the hazards with identification and evaluation leads lower the risk. The unique and ever-changing environment of research laboratory may involve a wide variety of hazards and some skills must be possessed by laboratory worker and they are hazard identification, hazard evaluation, and hazard mitigation. Integration of various hazard methodologies is based on their laboratory activities without compromising safety accepts and environment guidelines [2]. The Chemical Safety Board (CSB) in collaboration with American Chemical Society (ACS) to develop good practice guidance that identifies and describes methodologies to assess and control hazards that can be used successfully in a research laboratory. The ACS assigned the responsibility for this task to the ACS Committee on Chemical Safety (CCS) which

in turn with coordination of the division of Chemical Health and Safety created a guide for identifying and evaluating hazards, and managing the associated risks of these hazards in research laboratories [3]. The following factors were taken in consideration:

– Ensuring gatherization and analyzation of hazard
– The researchers are funded to provided there inputs and experiences on public platforms.
– Every activity is compared with various types of the techniques.
– Tools are reflects with different types of variables and tasks to aid the researchers to identify and retort the specific changes in both minor and major scale.

This will enhance laboratory safety and provides the elaborated in depth information on hazard analysis for those like to explore. Different tools may be used to conduct hazard assessments and they are:

1. Research laboratories are control of banding chemical usage: Hazards are categorized to the controlled strategies are necessary for appropriate approval of categorized chemicals usage.
2. Standard operating procedures (SOPs): A inclusive method of structured development to assessing the characteristics of study to lead the development of ideal SOPs.
3. Checklists: A list of precautionary methods to aid the researchers to be accurate functioning, which are hypothetical to take.
4. Job hazard scrutiny: Each and every step of the document of hazard is approached through methodology.
5. What-if analysis: The methodology to analyze the series queries to approach and identify to understand what the things, which go wrong.

Every methodology can be improved for betterment of precise needs for any user.

METHODOLOGY

The collection of literature on safety and SOP's with consent of the knowledgeable persons is necessary to evaluate the hazard properties [4]. Frontline laboratory workers always come in contact with different hazards and thus following steps are learning:

1. Unconscious ineffectiveness: if the person details with the unknown methodology and do not understand what to do, how to proceed.
2. Conscious ineffectiveness: if the person details with the known methodology with inadequate knowledge.
3. Conscious capability: if the person details with the methodology is able to serve with higher effectiveness and safety.
4. Unconscious capability: if the person details with the methodology with greater experience and knowledge on safely rules.

There are some points that are needed to be considered additionally are: perfection cannot be achieved in initial stages of any procedures of hazard evaluation, but significant development can be done by, 1) Open lines of communication should be

maintained about safety in research meetings; 2) Hazard evaluations should be published, so others can use them as examples.

Hazard Identification:

Potential chemical hazards are listed below:

- danger from contact with highly hazardous substances;
- danger from inhalation of vapors of harmful liquids, gases, dust, fog, smoke;
- the danger of substances that, due to reaction with alkalis, acids, amines, sulfur dioxide, thiourea, metal salts and oxidants, can contribute to fire and explosion;
- danger of formation of toxic fumes when heated;
- the risk of exposure to the skin of lubricating oils;
- the danger of exposure to the skin of cleaning and degreasing agents;
- hazards associated with exposure to aerosols of predominantly fibrogenic action:
- danger of exposure to dust on the eyes;
- the risk of damage to the respiratory system by dust particles;
- the risk of exposure to dust on the skin;
- the danger associated with the release of dust;
- the dangers of exposure to air suspension of harmful chemicals;
- the risk of exposure to the respiratory system of air suspensions containing lubricating oils;
- the risk of exposure to the respiratory system of air mixtures containing cleaning and degreasing agents, etc.

All of the hazardous functional groups of chemical compounds are derived from one or more of the some basic atomic groupings [5, 6] shown in Table 1.

The recognizing the existence of hazards is an important for the safety and for accomplishment of an adequate analysis [7]. A hazard creates substantial destruction, which can be due to any agent, condition, or any specific work left incomplete, which may lead unrestrained and could upshot potential damage of life, injuries, illness and property loss. In facts the identification of a conditions and agents are quite easier. It is often easier to identify agents or conditions of the any hazards, indeed it is challenging to identify the consequence and accompanying activities of the hazards.

Hazard Evaluation:

Classification of risk evaluation methods are presented in Figure 2.

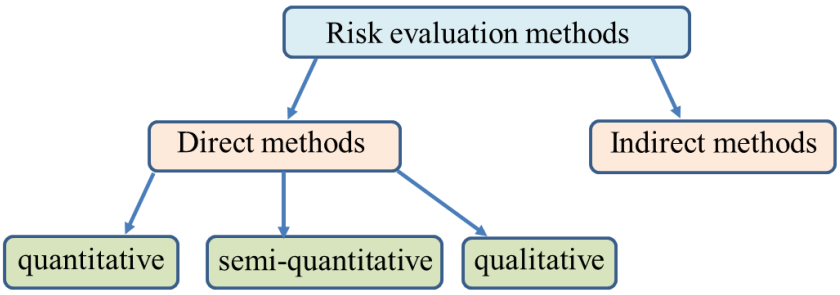
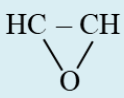


Fig. 2. Classification of risk assessment methods.

The hazard evaluation should be qualitative and quantitative for better sympathetic way. The hazard evaluation results of risk on conducted laboratory experiments may give the information on tools and techniques on risk management with how to elimination or substitution of materials/chemicals [8, 9]. The primary safety devices, PPE kits, engineering controls, operation of chemical fume hoods SOPs and processes should be updated.

Table 1. Example of Functional Groups that Indicate or May Enhance Molecular Instability

–C≡C–	Acetylenic
–C≡N–	Cyano
C–NO_2	Aryl, alkyl nitro
C–O–N=O	Alkyl nitrite
–C–N≡N	Diazo
N–N≡N	Azide
–C–O–O–H	Peroxyacids
C–O–O–C	Peroxyesters, peroxides
	Epoxides
	Azetidine
–O–X	Hypohalites
–ClO_3	Chlorates
=N–M	N–metal salts including azides

Hazard Controls Selection:

An effective safety performance the hazard controls and evaluation needs to follow and mandate to work properly through the “hierarchy of control”. The hierarchy of control may include in the order of controls related engineering, elimination, controls related administrative and PPE. The circumstances of the risk factors will be well compared with parameters of the controls selection [10].

Principal Investigator:

A principal investigator (PI) is responsible for managing sponsored research projects. The PI is chief responsible for any mitigation and analysis through organized strategical development in research laboratory. Other responsibilities related to safety, the PI should:

– For effective hazards mitigation the proper analysis and determination of suitable controls are needed;

- It is necessary to integrate the hazard analysis into research process;
- The persons in laboratory should understood and communicate about controls of any hazards;
- Involve in laboratory the daily maneuvers to ensure the performance of the workers upon controls;
- Addressing and elaborating the past incident lessons with workers of IN & OUT sides the laboratory improves the safety senses;
- Maintenance and periodical reviewing of the control are significant; and
- Certify the adequate training with complete documentation.

The laboratory assistant and/or manager and/or co-PI of the research laboratory may also visit to evaluate the SOP's, operation, performance and chemical hygiene. The PI play a vital role of the designating the person by education and experience on the field of chemical safety.

RESULTS AND DISCUSSIONS

The hazard analysis is the essential plan for health and chemical safety in the laboratory. The planning of research laboratory setup, organized protocols, training may minimize the incident in laboratories during the job. The job hazard analysis reports validate the operations, execution, training deficits, which leads to best practices [11]. The operative methodology eliminates the risk lowering the injuries and job productivities improve. The methodology is potential tool for every researcher and employees by furnishing SOPs, dependable steps needs for safe performance of any task. The inclusion of hazard information in research grants shows the obligation about chemical safety with best practices. The best practices observes the reference SOPs of the specific chemical, process, operation, process and hazard information with original checklist [12]. The chemical information like benzene solvent is comes under hazard, which causes cancer and causes fire. By placing the benzene chemical in flammable places with controllers helps the value added information to researches and employees. The various types of the controllers should be listed and visible to everyone for quick course of action. A job hazard analysis is the laboratory scale methodology. The following list provides few ideas of job hazard analysis might be appropriate:

- A complete documentation of previous incidents.
- Listing of the projects, which may cause the potential risk.
- Projects may organize the chemical handling, process SOPs to avoid any human error, which lead injury or fire.
- Every new trainee or researcher should acquainted to SOPs, before job cards.
- Every complex operation can be simplified by providing manuals and tools.
- Periodical training and mock drills makes best practices.

Pros:

- Initially every hazard can figure it out before the job and controls of the risk will be implemented.
- Some hazards identified during the preparation of a job hazard analysis can be completely eliminated during the planning phase.

– The job hazard analysis steps should be according to chemical experimental procedures.

Cons:

– Process or job steps can be missed—thereby overlooking hazards—without careful attention to detail.
– Assigning risk to determine level of control can be difficult. Risk is perceived differently by individuals based on their experience, knowledge, and tolerance level.

Limitations:

– Novice workers should always be guided during this process. Even experienced researchers should seek guidance when risks are being assigned to hazards outside their areas of expertise.

The job hazard analysis should adopt the hazard exercises in priority using identification of hazard and characterization of hazard.

Hazard Job Analysis:

A job hazard analysis is intended to evaluate to verify the hazard consequence with respective that job. The job hazard analysis concludes the liaising between researcher, required tools for any tasks to accomplish, type of task and location of task need to complete for active hazard mitigation. The institution is the primary party to involve in policy implementation to control the risk in all chemical aspects.

When This Method Should Be Used?

A job hazard analysis can be used by all researchers working in academic laboratories to analyze tasks that will be used in upcoming laboratory projects to list out the latent physical and chemical hazards for accurate measurements and controls shall be instigated. Any potential hazard cannot be eliminated by the risk(s) associated with the hazards can be reduced by using various methods of controls for specific job [13]. Indeed the hazard job analysis is significant tool prepared for specific chemical reaction, operations, process with all the details by respective laboratories. The hazard job analysis is gumshoe to track following points:

– The factors like reaction path, reaction equipment, reaction conditions and environmental are the possible pathways may go wrong.
– If the reaction consequences may lead potential risk compared with initial chemicals.
– The analysis of possible conditions may enable, which go wrong.
– The analysis of various indirect contributing factors.
– The above factors may conclude the how the incident occurred.

Hazard Evaluation through Check List

For any best practices for safety required the in effect tool of maintaining a proper check list. The check list are swotted by many experts to evaluate and identify the safety levels through specific methodology. The check list provides all the information of types operations, details about the level of risk materials and equipment safety [14]. Every research lab should have an imperative assistance of the

checklist methodology is quite helpful to measure and quantify the risk. This type of methodology will raise the consents of organization and researcher to perform the reasonable risk assessment and degree of impact [15, 16]. The organization should also prominence on resources, time and budget to avoid risk factors, which also fulfil the major and minor details of the safety compliances [17]. This check list also provides the missing information of operations, equipment, standard operating procedures, other aspects of job card, what-if analysis and risk assessment methods are shown in Table 2.

Table 2. Chemical Safety Levels as per suggested Assessment

Chemical Safety Levels as per suggested Assessment	Level 1	Level 2	Level 3	Level 4
Theoretical risk Level (based on suppleness and responsibility)	The hazard chemicals in laboratory are similar to any other chemicals used in household activities	Academic laboratory hazards are depend upon chemical inventory with proper protocols.	Academic laboratory hazards are depend upon moderate chemical inventory with proper protocols.	Extremely sever laboratory hazards are depend upon restricted chemical inventory with proper protocols.
Type of chemicals used in lab and other places.	The products of consumer with proper packing (unopened package of chemicals).	Chemicals of acid, base, salts, lower alcohols, compressed gases.	Chemicals of corrosives, flammable solvents & gases, milligram levels of pyrophoric materials.	Chemicals of highly reactive pyrophoric materials & gases compounds, lethal toxic materials of any state (solid, liquid, gas)

CONCLUSION

Every research laboratory may shoot the potential tread of hazard due to lack of knowledge on parameters like chemical operating procedures, chemical compound behavior, laboratory layout, laboratory assistant or researcher, estimation of toxicity and subsequent consequences. These parameters are need to evaluate periodically through classified safety methodologies by integrating the checklist, standard operating procedures and job hazard scrutiny. The checklist also need to include hazard identification with evaluation and safety devices need to display with regular exercises. Indeed, an effective hazard identification with evaluation the laboratory principal investigator and head of the institution are the prime role to control the responsibilities related to safety.

ACKNOWLEDGEMENT

I would like to thank the government organizations like National Authority of Chemical Weapon Conventions-India, National Disaster Management Authority-India and National Institute of Disaster Management-India for valuable inputs behind this article.

CONFLICT OF INTERESTS:

The authors declare no conflict of interests.

References:

1. King, R.W., & Magid, J. (1979). *Industrial Hazard and Safety Handbook*. Newnes-Butterworth, London. eBook ISBN: 9781483102191.
2. Center for Chemical Process Safety (CCPS), *Guidelines for Engineering Design for Process Safety* (New York: American Institute of Chemical Engineers, 1993). 12 Center for Chemical Process Safety (CCPS), Inherently Safer Chemical Processes: A Life Cycle Approach, 2nd ed. (Hoboken, NJ: John Wiley & Sons, 2009).
3. Holmstrom D., Altamirano F., Banks J., Joseph G., Kaszniak M., Mackenzie C., Shroff R., Cohen H., & Wallace S. (2006). CSB Investigation of the Explosions and Fire at the BP Texas City Refinery on March 23, 2005, *"Process Safety Progress*, *25*(4), 345–349. https://doi.org/10.1002/prs.10158
4. Craig Matthiessen R. (1986). Estimating Chemical Exposure Levels in the Workplace," *Chemical Engineering Progress 82*(4), 30–34. http://pascal-francis.inist.fr/vibad/index.php?action=getRecordDetail&idt=8693938 (accessed 07.06.2021)
5. Carson, P.; Mumford, C. *Hazardous Chemicals Handbook*, 2nd ed. Butterworth Heinemann; Oxford, UK, 2002, Ch. 7
6. Churchill, D. G. (2006) Chemical Structure and Accidental Explosion Risk in the Research Laboratory. *J. Chem. Ed.*, *83*(12), 1798–1803.
7. Jay A. Young (1991). *Improving Safety in the Chemical Laboratory: A Practical Guide* 2nd Edition, Wiley-Interscience; 2nd edition (June 1, 1991). ISBN-13: 978-0471530367
8. David G. Churchill (2006), Chemical Structure and Accidental Explosion Risk in the Research Laboratory, *J. Chem. Educ.*, *83*(12), 1798. https://doi.org/10.1021/ed083p1798
9. David J. Leggett (2012). Lab-HIRA: Hazard identification and risk analysis for the chemical research laboratory: Part 1. Preliminary hazard evaluation. *Journal of Chemical Health & Safety*, *19*(5), 9–24. https://doi.org/10.1016/j.jchas.2012.01.012
10. Zhihua Li, Wei Wang (2020). Lesson Learned from an Explosion during Chemical Synthesis: Discussion and Preventative Strategies. *ACS Chemical Health & Safety 27*(5), 272–278. https://doi.org/10.1021/acs.chas.9b00028
11. Paul Gruhn (1991). The pros and cons of qualitative & quantitative analysis of safety systems, *ISA Transactions*, *30*(4), 79–86. https://doi.org/10.1016/0019-0578(91)90011-S
12. Whiston, J. (ed.) (1991). *Safety in Chemical Production*, Blackwell Science, Oxford. ISBN 0632032553
13. Foster B.L. (2005). The chemical inventory management system in academia. *Journal of Chemical Health & Safety*, *12*(5), 21–25.
14. IPCS (International Programme on Chemical Safety). International Chemical Safety Cards. 2009. [September 15, 2009]. Available at www.cdc.gov/niosh. (accessed 07.06.2021)
15. Mallinkrodt Baker, Inc. *Material Safety Data Sheet #M1599*, August 20. Phillipsburg, NJ: Mallinckrodt Baker, Inc.; 2008. Mercury (CAS Number 7439-97-6)
16. Geetha Bhavani A., & Anil Kumar Gupta (2020). Effective Utilization of Databases for Preventing Chemical Accidents, *Khimicheskaya Bezopasnost' = Chemical Safety Science*, *4*(2), 24–34. https://doi.org/10.25514/CHS.2020.2.18002

17. Luxon, S.G. (ed.) (1992). *Hazards in the Chemical Laboratory*, 5th edn, London: Royal Society of Chemistry, ISBN: 0851862292 9780851862293.