

## **Risk Analysis of Occupational Health and Safety in the use of Gas Chromatography-Flame Ionisation Detector Using the House of Risk Safety, Health, etc Method**

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### **ABSTRACT**

*This study aims to analyze and evaluate occupational safety and health (OSH) risks associated with the use of Gas Chromatography-Flame Ionisation Detection (GC-FID) equipment at PT. XYZ's laboratory. The GC-FID tool combines gas chromatography for compound separation and flame ionisation detection for measuring organic compound concentrations. It plays a crucial role in maintaining product quality before cigarettes are packaged. The study identifies and maps potential hazards in three operational stages: startup, operation, and shutdown. Risks such as gas leaks, flammable gas leaks, and burns due to high temperatures (150–200 °C) were found. Currently, the OSH management relies on standard operating procedures and personal protective equipment (PPE) without a structured system in place. Using the Healthy, Etc (HORshe) risk analysis method, the study identified 10 risk events and 11 risk agents. Through this analysis, 13 preventive measures were developed to mitigate the identified risks. The expected outcome is to improve OSH management, reduce workplace accidents, and create a safer and healthier working environment. The study provides strategic recommendations to enhance OSH practices in the laboratory.*

**Keywords:** House of Risk Safety; Healthy; etc (HORshe); Risk Management; Gas Chromatography-Flame Ionization Detection (GC-FID).

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## **INTRODUCTION**

The implementation of Occupational Safety and Health (K3) is a form of effort to create a healthy, safe, and free workplace from environmental pollution so that it can reduce or be free from work accidents and occupational diseases which can ultimately increase work efficiency and productivity. Hazard is anything including a situation or action that has the potential to cause an accident or injury to a person, damage or other disturbance. Hazard is an inherent property and is part of a substance, system, condition or equipment. For example, fire, naturally contains heat properties that when it hits objects or human bodies can cause damage or injury.

Dangers in life are very many varieties and types. Unknowingly there are various types of hazards around us which include mechanical hazards, electrical hazards, chemical hazards, physical hazards, biological hazards, ergonomic hazards, and psychological hazards. All work accidents that occur have a causative factor. The causes of work accidents can be sourced from the work environment, equipment, and people themselves. To prevent work accidents, these causes must be eliminated. Eighty-five percent of the causes of accidents are human factors (Suma'mur, 2013). Therefore, safety efforts in addition to being aimed at mechanical engineering must also pay special attention to the human aspect.

Based on data obtained from Social Security, the number of work accidents tends to increase every year. As a reference, in 2010 there were 98,711 cases of work accidents, in 2011

there were 99,491 cases, in 2012 there were 103,074 cases, and in 2014 there were 103,283 cases of work accidents. According to data obtained from BPJS Ketenagakerjaan, the number of work accidents in 2016 reached an average of 226 cases per day. Of these cases, every day there are 20 people who are disabled, 7 people die and 1 person is totally disabled. Meanwhile, BPJS Employment data until October 30, 2017, there were 88,000 work accidents or an average of 303 cases per month. For the North Sumatra region with more than 1.1 million BPJS Ketenagakerjaan participants, there were 6,217 cases in 2017. This statistical data shows the urgency of implementing an effective and comprehensive K3 management system in various industrial sectors.

PT. XYZ is one of the largest cigarette manufacturers in Indonesia, having a production system that involves various complex processes, ranging from raw material processing, the use of high-tech machines, to product packaging and distribution. In each of these stages of production, there are various potential hazards that can have an impact on the safety and health of the workforce as well as the company's overall operations. PT. XYZ in carrying out its operations, is faced with various risks that need to be managed properly to ensure a safe and healthy working environment for all workers.

At PT. XYZ has a laboratory that aims to maintain the quality of raw materials until the finished product. One of the tools in the PT. XYZ stands for Gas Chromatography-Flame Ionization Detection (GC-FID) which is a chemical analysis tool that combines two technologies: gas chromatography (GC) to separate compounds in samples, and flame ionization detector (FID) to detect and measure concentrations of organic compounds. The purpose of this tool is to measure the product content of the primary department to maintain product quality before being wrapped into cigarette bars.

In the use of GC-FID it is divided into 3 stages, namely start up, running, and shutdown. From these three stages, there is a threat of accidents such as pressurized and flammable gas leakage that can be caused by improper installation of columns or connectors to gas leaks and burns due to the temperature at the inlet, oven, and detector reaching 150-200°C. In operation, GC-FID does not have good occupational safety management, only using operating standards and PPE. Some accidents have occurred due to the use of GC-FID, such as burns caused during the shutdown process not waiting for the inlet temperature and detector to reach normal temperature and there is no information from previous shifts related to the GC-FID cooling process. When he wanted to remove the column, the operator suffered burns due to the column that was still hot.

From this information, it shows that the risk is real and needs serious attention. These accidents indicate weaknesses in risk management and safety procedures implemented during the operation of GC-FID machines. Therefore, systematic and thorough risk observation and analysis is required to identify hazards that may arise, as well as to design effective control measures.

To overcome these challenges, a fast, effective and efficient risk management system is needed. One of the methods that can be used is the House of Risk Safety, Health, etc (HORShe). HORShe is a model based on the need for risk management that focuses on preventive measures to determine which types of risks are prioritized and then given risk mitigation or countermeasures. The HORShe method is a development of the House of Risk (HOR) method

which has been widely used in supply chain risk management, but is specially adapted for the context of occupational safety and health.

Based on the background that has been described, the formulation of the problem raised in this study is how effective the HORshe method is in identifying and reducing work risks in the laboratory environment of PT. XYZ, especially in the operation of GC-FID tools?

This study has several specific objectives, namely: (1) Analyzing the risks in the GC-FID tool in more detail using the House of Risk Safety, Health, etc (HORshe) method; (2) Identify risk events that may occur based on the type of activities carried out by workers; (3) Identify risk agents that cause risk events; and (4) Determine the priority of the most effective and relevant risk preventive actions to be implemented in the Laboratory of PT. XYZ.

## **METHOD**

### **Research Design**

This research is a qualitative and quantitative research (mixed method) with a semi-quantitative approach using the House of Risk Safety, Health, etc (HORshe) method. The research was carried out at the Laboratory of PT. XYZ is located in Surabaya, Indonesia. The research period was conducted from August 2025 to December 2025, including the observation stage, data collection, data analysis, and preparation of recommendations. The HORshe method was chosen for its ability to integrate risk assessment with systematic planning of preventive measures, which is well suited to the context of occupational safety and health in the laboratory.

### **Research Respondents**

Research respondents are an important aspect in the continuity of research to support the accuracy of assessment and equalize perceptions between researchers and workers who are experts in related fields. The study respondents were selected with specific criteria to ensure the validity and reliability of the data collected. The respondent criteria include: (1) Employees of the Health, Safety, Environment (HSE) Division as the responsible party and related to Occupational Safety and Health (K3) at the PT. XYZ; (2) The operator as the party responsible for the operation of the GC-FID Agilent 7890A device with at least 1 year of work experience; and (3) The head of the laboratory or supervisor who is responsible for all activities in the Laboratory of PT. XYZ.

All employees in the Health, Safety, Environment (HSE) Division are experts or expertise in the field of K3 because they have a General K3 Expert Certification. This is the minimum requirement to be able to work in the field of K3 at the relevant company. As for the operator, laboratory heads, and supervisors have experience related to use, standard operating procedures (SOPs), and working environment conditions on the Agilent 7890A Gas Chromatograph-FID machine. The total number of respondents involved in this study was 8 people consisting of 3 people from the HSE Division, 3 GC-FID operators, 1 laboratory head, and 1 laboratory supervisor.

### **Data Collection**

Data collection is carried out through several complementary approaches to ensure the completeness and accuracy of information. Primary data were collected through: (1) Direct observation at the research site to understand the existing conditions and operational activities of workers in the laboratory area using GC-FID. Observations are carried out during normal operational periods to identify potential hazards and risks that may occur; (2) In-depth

interviews with HSE Division employees, operators, and laboratory supervisors to obtain information on experience, risk perception, and occupational safety practices applied; (3) Focus Group Discussions (FGDs) with relevant stakeholders to identify and validate risk events and risk agents that have been identified.

Secondary data was collected from the company which included: (1) GC-FID operating standard operating procedures (SOPs); (2) Records of work accidents and incidents that have occurred in the laboratory; (3) Technical documents regarding the specifications and maintenance procedures of GC-FID Agilent 7890A; (4) K3 policies and programs that have been implemented at PT. XYZ; and (5) Training and certification data owned by laboratory operators and officers. All data collected is then validated through triangulation of sources and methods to ensure its validity and reliability.

### **Implementation of the HORshe Method**

The HORshe method is implemented in three main stages that follow a systematic framework for risk analysis and the development of preventive measures. Phase 1 focuses on risk identification and assessment. At this stage, the following are carried out: (a) Identification of risky worker operational activities in the laboratory area using direct observation and analysis of work processes; (b) Identification of risk events ( $E_i$ ) that may occur based on the type of activity carried out by the worker. Risk events are categorized based on the SHELL Model (Software, Hardware, Environment, Liveware-Liveware) to understand the interactions between various system elements that can trigger risks; (c) Identification of risk agents ( $A_j$ ) that are the cause or trigger of risk events through cause-and-effect analysis and validation with expert judgment.

Furthermore, an assessment was carried out on: (1) Severity ( $S_i$ ) of each risk event based on the impact on four factors, namely people, environment, company, and company assets using a scale of 1 to 5. The severity assessment follows the standard category from insignificant (1), minor (2), moderate (3), major (4), to catastrophic (5); (2) Occurrence probability ( $O_j$ ) of each risk agent indicating how often the risk cause occurs or arises, using a scale of 1 to 5 where scale 1 indicates very rare and scale 5 indicates very frequent; (3) Detection ( $D_j$ ) of each risk agent that indicates how difficult the risk cause is to be detected, using a scale of 1 to 5 where scale 1 indicates very easy to detect and scale 5 indicates very difficult to detect.

The assessment of the relationship ( $R_{ij}$ ) between risk events and risk agents was also carried out using a scale of 0, 1, 3, or 9, where 0 indicated no relationship, 1 indicated a weak relationship, 3 indicated a moderate relationship, and 9 indicated a strong relationship. This assessment is based on secondary data, direct observations, and consensus from discussions with workers who are experts in the relevant field. After all values are determined, the Aggregate Risk Potential ( $ARP_j$ ) is calculated for each risk agent using the formula:  $ARP_j = O_j \times D_j \times \Sigma(S_i \times R_{ij})$ . Risk agents are then sorted by ARP values from highest to lowest to determine the priority of preventive measures.

Phase 2 focuses on the design of preventive actions. At this stage, the following are carried out: (a) Creation of a Pareto diagram to focus the risk agents to be analyzed and the formulation of preventive measures. Pareto charts help identify the risk agents that contribute most significantly to total risk (80/20 principle); (b) Identification and determination of preventive actions (PA $k$ ) that are appropriate to priority risk agents. Preventive measures are designed based on a hierarchy of risk control from elimination, substitution, engineering

engineering, administrative, to personal protective equipment; (c) An assessment of the relationship between preventive measures and risk agents using a scale of 0, 1, 3, or 9 to determine how effective preventive measures are in addressing a particular risk agent.

Then a difficulty level (Dk) was determined in implementing each preventive measure using a scale of 1 to 5, where scale 1 showed very easy to implement and scale 5 showed very difficult to implement. The level of difficulty considers factors such as cost, implementation time, availability of resources, technical complexity, and acceptance from workers. From this assessment, the Total Effectiveness to Difficulty Ratio (TEDRk) is calculated, which is the ratio between the total effectiveness of preventive measures and the level of difficulty in their implementation. Preventive measures with the highest TEDR values are prioritized for implementation because they provide maximum effectiveness with a relatively manageable level of difficulty.

Phase 3 focuses on assessing residual risk after preventive measures are implemented. At this stage, a prediction is made of: (1) The severity value of each risk event after the preventive measures are applied, taking into account how the preventive measures reduce the impact of risk events on people, the environment, companies, and assets; (2) The value of the occurrence probability of each risk agent after the preventive measures are applied, taking into account how the preventive measures reduce the frequency of occurrence of risk agents; (3) The detection value of each risk agent after the preventive measures are applied, taking into account how the preventive measures improve the ability of early detection of risk agents. The prediction of these values is carried out based on expert judgment and confirmed through discussions with the K3 team and operators. Once the predicted value is determined, the residual ARP value is recalculated to evaluate the effectiveness of the proposed precautions.

### **Data Analysis**

Data analysis was carried out using the HORshe spreadsheet application which has been specially developed to calculate ARP values, determine risk prioritization, and formulate preventive measures. The SHELL (Software, Hardware, Environment, Liveware, Liveware) model is used as a framework to categorize business processes and understand the interactions between system elements. Risk assessment uses pre-established criteria for severity, occurrence, and detection scales. Risk priorities are determined based on the ARP rating, and a Pareto chart is used to focus on the most critical risk agents. Qualitative data from interviews and observations were analyzed using content analysis techniques to identify key themes related to occupational safety practices and risk perception. Data triangulation is done by comparing data from various sources to ensure the validity of research findings.

## **RESULTS AND DISCUSSION**

### **Identification of Worker Activities in the Laboratory of PT. XYZ**

At the PT. XYZ, in general, production is divided into two departments, namely primary and secondary. The primary department is tasked with processing raw materials such as tobacco and cloves which will later be given flavors or flavors and mixed evenly. Meanwhile, the secondary department is in charge of processing the mixed results from the primary department which are wrapped and made into cigarette bars and then packaged into cigarette packages. The use of GC-FID Agilent 7890A is used to ensure that every output from the primary department is always uniform starting from the organic content contained in it. Sampling is

carried out periodically in order to find out if there are changes in each production result. Therefore, the expected results of GC-FID have accuracy in each result to maintain the quality of each product.

GC-FID's operational activities are divided into three main stages, namely start-up, running, and shutdown. At the start-up stage, the operator prepares the equipment which includes checking the condition of the carrier gas, checking the temperature and pressure of the system, installing chromatography columns, and calibrating detectors. The running stage includes sample injection, monitoring the analysis process, and reading of chromatogram results. Meanwhile, the shutdown stage involves gradually lowering the system temperature, closing the gas flow, and cleaning the equipment components. Each operational stage has different potential hazards and risks that need to be identified and managed properly.

**Identify Risk Events**

Based on observations, interviews, and analysis of secondary data, 10 risk events (E<sub>i</sub>) have been identified in GC-FID operational activities at the PT. XYZ. Risk events are categorized based on the interaction of the SHELL Model to understand the relationships between different system elements that can trigger risks. Identified risk events include: (E1) High-voltage electric shock at Liveware-Hardware (L-H) interactions; (E2) Touching the machine when the temperature is still high at Liveware-Liveware (L-L) interaction; (E3) Carrier gas leakage at Liveware-Hardware (L-H) interaction; (E4) Damage to the Micro-Electron Capture Detector (μECD) in Liveware-Hardware (L-H) interactions; (E5) Sample injection error on Liveware-Liveware (L-L) interaction; (E6) Overheat in the GC column at the Liveware-Hardware (L-H) interaction; (E7) Inadequate ventilation ducts at Liveware-Hardware (L-H) interactions; (E8) Errors in the analysis program on Liveware-Environment (L-E) interactions; (E9) SOPs that still use old-type analysis tools in Liveware-Software (L-S) interactions; and (E10) Room temperature and humidity are unstable at Liveware-Software (L-S) interactions.

**Risk Event Severity Assessment**

Severity assessment is carried out to find out how much of an impact the risk event causes. The assessment was carried out on four aspects that can be affected, namely the human aspect (human impact), the environmental aspect (environment impact), the corporate aspect (company impact), and the company asset aspect (asset impact). The highest severity value of the four aspects is assumed as the severity value for the associated risk event. The results of the severity assessment showed that three risk events had the highest severity values (scale of 5), namely E3 (Carrier gas leakage), E4 (Damage to μECD), and E7 (Inadequate ventilation duct). These three risk events have the potential for very serious impacts that can cause fatality, significant environmental damage, and large asset losses.

**Table 1. Severity Assessment for Risk Events**

Code	Risk Occurrence	Category SHELL	Severity (S <sub>i</sub> )
E1	Touching the engine when the temperature is still high	L-L	4
E2	Sample injection error	L-L	4
E3	Carrier gas leakage	L-H	5
E4	Damage to the Micro-Electron Capture Detector	L-H	5
E5	High voltage electric shock	L-H	3

Code	Risk Occurrence	Category SHELL	Severity (Si)
E6	Overheat on GC columns	L-H	4
E7	Inadequate ventilation ducts	L-H	5
E8	Errors in the analysis program	L-S	3
E9	SOPs that still use old type analysis tools	L-S	2
E10	Room temperature and unstable humidity	L-E	2

*Source: Research Data (2025)*

Carrier gas leaks (E3) have the highest severity value because carrier gases such as hydrogen are flammable and can cause fatal explosions. Damage to the Micro-Electron Capture Detector (E4) also received a high severity value because this component contains radioactive substances even in small amounts, but if not handled appropriately, it can endanger workers and require very expensive repair costs. Inadequate ventilation ducts (E7) received a high severity score because they can cause the accumulation of harmful gases that can cause respiratory distress to gas poisoning for workers in the laboratory.

### **Identification and Assessment of Risk Agents**

From the risk identification process, it was found that there were 11 risk agents (AJ) which were the cause of 10 risk events in GC-FID operational activities. Identified risk agents include: (A1) Lack of understanding of SOPs and the importance of PPE use; (A2) Lack of focus in carrying out maintenance; (A3) Inappropriate use of PPE by workers; (A4) Workers do not comply with work instructions and SOPs; (A5) Open electrical (cable) installation; (A6) Inadequate or too far away fire extinguisher; (A7) Limited employee knowledge of hazards; (A8) The quality of the equipment is poor; (A9) Cooling system failure; (A10) Poor air ventilation; and (A11) The absence of a temperature and air humidity control device.

Each risk agent was assessed based on occurrence probability (Oj) and detection difficulty (Dj) using a scale of 1 to 5. Occurrence assessment shows how often risk agents occur or appear in day-to-day operations. Detection assessments show how difficult it is for those risk agents to be detected before they cause a risk event. The relationship between risk events and risk agents is assessed using a scale of 0, 1, 3, or 9 which indicates the level of closeness of the relationship from no relationship to very strong relationship. This assessment was conducted based on secondary data, direct observation, and discussions with research respondents to ensure the accuracy and validity of the assessment.

### **Calculation of Aggregate Risk Potential and Risk Priority**

After determining the severity, occurrence, detection, and relationship values, the Aggregate Risk Potential (ARP) for each risk agent was calculated using the formula  $ARP_j = O_j \times D_j \times \sum(S_i \times R_{ij})$ . The results of the ARP calculation are then sorted to determine the 10 priority risk agents that require preventive measures. Based on the ARP calculation, the risk agents with the highest scores were A1 (Lack of understanding of SOPs and the importance of using PPE), A7 (Limited employee knowledge of hazards), and A10 (Poor air ventilation). The Pareto chart was created to visualize the cumulative contribution of the priority risk agents to the total risk, which shows that the 10 priority risk agents contribute approximately 80% to the total ARP value.

### Precautionary Measures Design (HORshe Phase 2)

In the second phase of HORshe, preventive measures were designed to address 10 priority risk agents. A total of 13 preventive measures were successfully formulated covering technical and non-technical aspects. These preventive measures include: (PA1) Conducting K3 training and periodic refresher training on SOPs; (PA2) Implement preventive maintenance schedules and inspection checklists; (PA3) Provide appropriate PPE and monitoring of usage compliance; (PA4) Implement a work permit and supervision system; (PA5) Conducting audits of electrical installations and repairs; (PA6) Adding fire extinguishers in strategic locations; (PA7) Conducting hazard awareness training; (PA8) Implementing equipment quality assurance programs; (PA9) Installing a backup cooling system; (PA10) Installing exhaust fans and ventilation repairs; (PA11) Installing a temperature and humidity monitoring system; (PA12) Develop comprehensive emergency response procedures; and (PA13) Implementing behavior-based safety programs.

**Table 2. Priority Precautions**

Code	Precautions	Priority Ranking
PA1	Conducting regular K3 training and refresher training on SOPs	1
PA2	Implement preventive maintenance schedules and inspection checklists	2
PA3	Provide appropriate PPE and usage compliance monitoring	3
PA10	Installing exhaust fans and venting repairs	4
PA7	Conducting hazard awareness training	5

*Source: Research Data (2025)*

Each preventive measure is assessed for its effectiveness in addressing risk agents and the level of difficulty in their implementation. The assessment of the relationship between preventive measures and risk agents uses a scale of 0, 1, 3, or 9. The difficulty level is assessed using a scale of 1 to 5, where scale 1 indicates very easy to implement and scale 5 indicates very difficult to implement. From this assessment, the Total Effectiveness to Difficulty Ratio (TEDR) is calculated to determine the priority of implementing preventive measures. Preventive measures with the highest TEDR values are prioritized because they provide maximum effectiveness with a relatively manageable level of difficulty.

### Residual Risk Assessment (HORshe Level 3)

The third stage of HORshe evaluates the residual risk after precautions are implemented. Predictions of severity, occurrence, and detection values were carried out for each risk event and risk agent after the implementation of preventive measures. Predictions are made based on expert assessments and discussions with the K3 team and operators. The results showed that after the implementation of priority preventive measures, there was a significant decrease in ARP values for most risk agents. This indicates that the proposed precautions are effective in reducing the risk of K3 in GC-FID operations. Nevertheless, some risk agents still require additional attention and ongoing monitoring to ensure their risks remain at acceptable levels.

### Discussion

The findings of the study show that the HORshe method is effective in identifying and prioritizing K3 risks in GC-FID operations. The strength of this method lies in a systematic approach in linking risk events to the causative agents and then designing targeted preventive measures. The use of the SHELL Model helps in categorizing business processes and

understanding the interaction between various system elements (Software, Hardware, Environment, Liveware). This categorization facilitates a more comprehensive understanding of how risks arise from various interactions within the work system.

The risk events with the highest severity levels identified were carrier gas leakage (E3), damage to the Micro-Electron Capture Detector (E4), and inadequate ventilation systems (E7), all with a severity score of 5. These risks have the potential to cause deaths, multiple casualties, substantial environmental damage, and significant asset damage. The high severity of these risks underscores the importance of implementing robust preventive measures and maintaining strict adherence to safety protocols. Occurrence and detection assessments for risk agents reveal that some agents are frequent and difficult to detect at the same time, making them particularly dangerous. For example, lack of understanding of SOPs and the importance of PPE, inappropriate use of PPE, and limited employee knowledge of hazards were found to have a high incidence rate and moderate to high detection difficulty level.

The preventive measures proposed in this study address both technical and human factors. Technical precautions include the implementation of preventive maintenance schedules, the implementation of electrical installation audits, the installation of backup cooling systems, and ventilation repairs. Human factors prevention measures include the implementation of K3 training, the implementation of the work permit system, the provision of appropriate PPE, and the development of behavior-based safety programs. This holistic approach is very important because, as noted by Suma'mur (2013), 85% of the causes of accidents are human factors. Therefore, addressing the human factor through training, awareness programs, and behavioral interventions is just as important as the implementation of technical controls.

The findings of the study are consistent with previous research on the application of HORshe in industrial settings. Similar to the study on oil and gas production station risks, the study shows that HORshe can effectively identify priority risk agents and formulate targeted preventive measures. Nevertheless, this study contributes to the literature by applying HORshe specifically to the operational of analytical laboratory equipment, expanding the application domain of the method. Residual risk assessments show that the implementation of preventive measures significantly reduces the overall risk level. However, continuous monitoring and periodic reassessments are still necessary to ensure that risks remain at acceptable levels and to identify new risks that may arise as operational changes and conditions change.

## **CONCLUSION**

This study successfully applied the House of Risk Safety, Health, etc (HORshe) method to analyze and evaluate Occupational Safety and Health risks in the operation of the Gas Chromatography-Flame Ionization Detector (GC-FID) at the Laboratory of PT. XYZ. The study identified 10 risk events and 11 risk agents through systematic observation, interviews, and data analysis. Risk assessments reveal that carrier gas leaks, damage to Micro-Electron Capture Detectors, and inadequate ventilation systems have the highest levels of severity with potentially catastrophic consequences. HORshe analysis prioritizes 10 risk agents based on Aggregate Risk Potential values, focusing attention on the most critical safety issues. A total of 13 preventive measures were formulated to address these priority risks, combining technical controls such as equipment maintenance and environmental improvements with human factor

interventions including training programs and behavioral safety initiatives. The calculation of the Total Effectiveness to Difficulty Ratio helps prioritize the implementation of preventive measures, with K3 training, preventive maintenance, and the provision of PPE getting the highest ranking. Residual risk assessments show that the implementation of these preventive measures significantly reduces the overall risk level, although continuous monitoring remains essential. Based on these findings, it is recommended that PT. XYZ systematically implements priority precautions, establishes regular K3 training programs, develops comprehensive maintenance schedules, improves ventilation systems, and creates a culture of safety awareness among all personnel. Follow-up research should monitor the long-term effectiveness of the implemented measures and explore the application of HORs to laboratory operations and other types of analytical equipment.

## REFERENCES

- Agung Budiyanto, dan Ismail. (2015). *Pengetahuan dan Sikap Pekerja Dalam Penggunaan Alat Pelindung Diri Pada Industri Informal Pengelasan di Desa Singajaya, Indramayu. Jurnal Kesehatan Masyarakat*. Vol.1. No.3. Hal.19.
- Anizar (2009), *Teknik Keselamatan Dan Kesehatan Kerja Di Industri*. Yogyakarta: Graha Ilmu.
- Geraldin, L. H., & Pujawan, I. N. (2009). *Application of House of Risk (HOR) Models for Risk Mitigation of Supply Chain Management*. *Jurnal Teknik Industri*, 11(2), 91–102.
- Hadi, P. N. (2019). *Identifikasi Risiko Rantai Pasok dengan Metode House of Risk (HOR)*. *Jurnal Performa: Media Ilmiah Teknik Industri*, 19(2), 89–100.
- Jamaludin Ramlan dan Sumihardi (2018), *Sanitasi Industri Dan K3, Bahan Ajar Kesehatan Lingkungan, Pusat Pendidikan Sumber Daya Manusia Kesehatan Badan Pengembangan Dan Pemberdayaan Sumber Daya Manusia Kesehatan, Kementerian Kesehatan Republik Indonesia*
- Molloy, G. J., & O, C. A. (2005). *The SHELL Model: A Useful Tool for Analyzing and Teaching the Contribution of Human Factors to Medical Error*. *Academic Medicine*, 80(2), 152–155. <https://doi.org/https://doi.org/10.1201/b16656>
- Pujawan, I. N., & Geraldin, L. H. (2009). *House of Risk: A Model for Proactive Supply Chain Risk Management*. *Business Process Management Journal*, 15(6), 953–967. <https://doi.org/10.1108/14637150911003801>
- Ramli S. (2009), *Manajemen Risiko dalam Perspektif K3*. Jakarta: Dian Rakyat.
- Suma'mur. (2014), *Higiene Perusahaan dan Kesehatan Kerja (Hiperkes)*. Edisi 2. Sagung Seto: Bandung
- Rika Ameiliawati (2022), *Penerapan Keselamatan dan Kesehatan Kerja dengan Metode HIRADC (Hazard Identification, Risk Assessment and Determining Control) di Area Plant Warehouse*, Departemen Kesehatan dan Keselamatan Kerja, Fakultas Kesehatan Masyarakat, Universitas Airlangga
- Siti Zahara (2018), *Hubungan Pengetahuan Keselamatan dan Kesehatan Kerja (K3) dengan Kecelakaan Kerja pada Tukang Las di Kecamatan Medan Kota tahun 2018*, Skripsi, Fakultas Kesehatan Masyarakat, Universitas Sumatera Utara, Medan
- Soedirman, (2014), *Kesehatan Kerja Dalam Perspektif Hiperkes & Keselamatan Kerja*. Jakarta: Erlangga

Sudiarno, A. (2024). *Faktor Manusia pada Sistem Keselamatan* (R. S. Dewi, R. Widyaningrum, D. S. Dewi, & N. P. Maharani, Eds.). Deepublish.

Suma'mur. P. K. (2013), *Higiene Perusahaan Dan Kesehatan Kerja (HIPERKES)*. Jakarta: Haji Masagung