Formosa Journal of Multidisciplinary Research (FJMR)
Vol. 4 No. 7, 2025: 3235-3246

Integration of Ion Mobility Spectrometry (IMS) Technology in Chemical Disaster Response Command System

Albertus Digwijaya Anindyajati[1*], Syamsul Maarif[2], Ernalem Bangun[3]
Defense Management Studies, Faculty of National Security,
Republic of Indonesia Defense University
Corresponding Author: Albertus Digwijaya Anindyajati 83081645@polri.go.id

ARTICLEINFO

Keywords: Gas Detection, Ion Mobility Spectrometry, Chemical Disasters, Emergency Response, Portable Devices

Received : 16, June
Revised : 30, June
Accepted: 24, July

ABSTRACT

Chemical disasters from industrial accidents or sabotage require swift, precise responses. This study examines the effectiveness of integrating gas detection equipment, particularly Ion Mobility Spectrometry (IMS), in enhancing preparedness and early response. Through a review of technical literature and device specifications, it found that IMS-based portable tools significantly improve real-time detection of toxic gases, aiding in rapid source identification, personnel safety, and tactical decision-making. The study highlights the importance of equipment standardization, specialized personnel training, and incorporating detection systems into national chemical disaster response protocols to strengthen operational readiness and response efficiency.

DOI: https://doi.org/10.55927/fjmr.v4i7.301
ISSN-E: 2829-8896
https://npaformosapublisher.org/index.php/fjmr

INTRODUCTION

Chemical disaster incidents, whether originating from industrial accidents, installation leaks, or chemical-based acts of terrorism, are multidimensional threats that not only impact public safety, but also harm national security and environmental resilience (Lippin et al., 2006a). In recent decades, the complexity of chemical compounds used in various industrial sectors has increased the risk of exposure to toxic and corrosive agents (Reed et al., 2019), which is often undetectable to the naked eye and can spread quickly through air, water, or surface contact.

Therefore, the ability to perform early detection of the presence of toxic gases is one of the most vital elements in a chemical emergency response system (Detection & Locations, 2021). Traditional approaches relying on visual inspection and manual assessment have proven inadequate in the face of modern chemical contamination dynamics (Kujawińska & Vogt, 2015). A technological solution is needed that is not only responsive, but also adaptive to field conditions and capable of providing data-based information in real time (Lyu et al., 2023a).

One technology that addresses this challenge is ion mobility spectrometry (IMS), which enables the detection of chemical compounds at very low concentrations within seconds. IMS-based portable gas detectors have been widely used in various military operations, homeland security, and disaster relief due to their ability to simultaneously identify compounds such as chlorine, ammonia, hydrogen sulfide, and volatile organic compounds (VOCs) (Ahrens et al., 2022a). The portability, durability against extreme conditions, and connectivity capabilities make this device very suitable for use in tactical operations in the field.

However, the effectiveness of technology does not lie in the device alone, but also in how the device is integrated into the task force's operational systems, training protocols, and national policies (Department of Homeland Security et al., nd)In the Indonesian context, the integration of chemical detection into national standard operating procedures (SOPs) and intensive training for the Indonesian National Police's KBRN (Chemical, Biological, Radiological, and Nuclear) units are urgent strategic needs.

This study aims to evaluate the effectiveness of integrating IMS-based gas detection devices in supporting chemical disaster preparedness and initial response. Furthermore, the study provides technical and policy recommendations to strengthen field operational capabilities in the face of increasingly complex chemical threats.

Although studies on chemical detection using IMS technology have been conducted globally, there is a limitation in studies examining the functional integration of these devices into national disaster command schemes, particularly in the context of developing countries like Indonesia. Previous research tends to focus on technical aspects or laboratory testing, with few systematically evaluating their effectiveness in complex and integrated field emergency response scenarios. Therefore, this study fills this gap by providing a critical evaluation of the adoption of IMS technology in an ICS-based national emergency response system (Joshi, 2024).

LITERATURE REVIEW

Ion Mobility Spectrometry (IMS) has been widely applied in the domains of security, military, and disaster response due to its ability to detect chemical substances at very low concentrations, in real-time, and with high portability (Joshi, 2024). This technique operates by separating ions based on their mobility in an electric field and has demonstrated effectiveness in detecting nerve agents, industrial toxic gases, and volatile organic compounds (VOCs).

Comparative studies have highlighted IMS's advantages over other detection technologies such as Gas Chromatography (GC) and Fourier Transform Infrared Spectroscopy (FTIR) in terms of speed and field adaptability. However, IMS may have lower selectivity in complex chemical environments, making integrated approaches like GC-IMS more favorable in practice (Haley & Romeskie, 1998).

From a disaster management perspective, (Lyu et al., 2023b) propose an integrated model that combines IMS technology with the Incident Command System (ICS) and digital command platforms. Their study demonstrates how such integration facilitates real-time decision-making and enhances response coordination through geospatial mapping and data visualization.

Moreover, (Chen et al., 2021) explore how IMS data can be augmented with artificial intelligence (AI) and machine learning to predict contaminant dispersion patterns. Their findings reveal that machine-learning-enhanced IMS systems can anticipate the spread of toxic gases more accurately, thereby improving early warning capabilities.

In the context of developing countries, the implementation of IMS faces several critical challenges. (Masekela et al., 2018) emphasize that limited access to advanced equipment, lack of standardized training, and the absence of regulatory frameworks hinder effective adoption. These constraints necessitate national capacity building and policy-level integration.

International standards such as NATO STANAG 4632 and the UNDRR guidelines advocate for the deployment of IMS as part of a broader CBRN (Chemical, Biological, Radiological, and Nuclear) monitoring system to ensure interoperability and real-time situational awareness across agencies. Recent sudy from Yu et al. (2024) show that liquid ammonia leakage emergency treatment system that includes concentration sensors and image acquisition devices for monitoring ammonia storage buckets, enhancing leak detection accuracy and reducing false alarms.

In conclusion, while IMS offers significant technical advantages, its effectiveness in national disaster response systems depends heavily on strategic integration into institutional protocols, operator training, and a comprehensive regulatory framework. This literature review highlights the urgent need for standardized implementation strategies and investments to harness the full potential of IMS technology in chemical disaster preparedness and response.

METHODOLOGY

This research employed a descriptive-qualitative method with a literature review approach. Data sources included user manuals for IMS-based gas detection equipment, device technical specifications, user training reports, and scientific references from chemistry and disaster journals. The analysis was conducted by examining the device's technical capabilities in detecting hazardous gases, its operational usability in the field, and its integration within an Incident Command System (ICS)-based emergency response framework.

The main data sources in this study include:

1. Technical documents from IMS device manufacturers, such as ChemProX and LCD 3.3, include specifications, usage protocols, and operational standards.
2. Academic literature from national and international journals discussing IMS, gas detection technology, and data-driven disaster response.
3. National policies and institutional regulations, including the Head of BNPB Regulation, the Indonesian National Police SOP, and the Indonesian version of the ICS document.
4. International study reports and guidelines, such as those from the United Nations Office for Disaster Risk Reduction (UNDRR) and the Department of Homeland Security (DHS-USA).

The analysis was conducted using content analysis techniques on the collected documents and literature. This process included identifying key themes such as the operational effectiveness of the IMS, integration into the command system, and constraints and opportunities for its implementation in Indonesia. IMS technical data was functionally compared to the needs of chemical emergency response in the field, including factors such as equipment mobility, sensitivity, response time, and digital connectivity. Data validity was strengthened by source triangulation, comparing equipment specifications with operational experience reported in official publications and tactical simulation results.

This literature review highlights the importance of rapid response in chemical disasters (Lippin et al., 2006b) and the need for an adaptive data-driven gas detection system(Dodds & Baker, 2019a). IMS technology offers a rapid detection solution with high sensitivity to a wide range of chemical agents (Ahrens et al., 2022b)This research is rooted in the theory of the Incident Command System (ICS), which emphasizes real-time information-based decision-making and interoperability between response units. The technology integration model within the ICS refers to the Command-Control-Communication (C3) framework, which supports efficient coordination during a crisis (Lyu et al., 2023c).

With this approach, the research is expected to provide a comprehensive picture of the preparedness and real contribution of IMS in strengthening early detection strategies and decision-making in the national chemical disaster response system.

RESEARCH RESULTS AND DISCUSSION

Working Principle of Ion Mobility Spectrometry (IMS)

Ion Mobility Spectrometry (IMS) is an analytical detection technique that utilizes differences in ion mobility in an electric field to separate and identify chemical molecules. A contaminated air sample is first ionized using an ionization source (such as a corona discharge), then the resulting ions are driven through a drift tube by an electric field (Cumeras et al., 2015)The difference in drift time of each ion provides a unique trace (ion mobility fingerprint) that can be used to identify specific chemical compounds.

The main advantages of IMS lie in:

a. Fast: Can provide results in less than 10 seconds.
b. Portable and lightweight: Suitable for field personnel.
c. It does not require a vacuum or complicated cooling, unlike mass spectrometry.
d. High sensitivity to volatile organic compounds (VOCs) and toxic chemical agents, even at parts per billion (ppb) concentrations.

This technology has been proven effective in detecting a variety of hazardous chemical agents including nerve agents, blister agents, and toxic industrial gases such as chlorine and ammonia (Dodds & Baker, 2019b).

However, this technology also has challenges. One of these is the potential for cross-interference from compounds with similar ionic mobility, especially in chemically complex environments. Therefore, IMS detection is often complemented by other techniques such as gas chromatography (GC-IMS) to increase selectivity (Ahrens & Zimmermann, 2021).

Figure 1 shows the working principle of Ion Mobility Spectrometry (IMS), which is the separation and detection of ions based on their speed of movement in an electric field. A gas sample enters through the sample inlet and is ionized in the ionization chamber using a source such as a corona discharge. The resulting ions are directed to the drift region by an electric field after passing through a shutter grid, which regulates the entry time of the ion packets. In a drift tube containing neutral gas, the ions experience different resistances depending on their size, shape, and charge, so they reach the Faraday plate (detector) at different times (drift time). This time difference is interpreted as the specific chemical identity of the detected compound, enabling IMS to identify various toxic compounds quickly, sensitively, and portably.

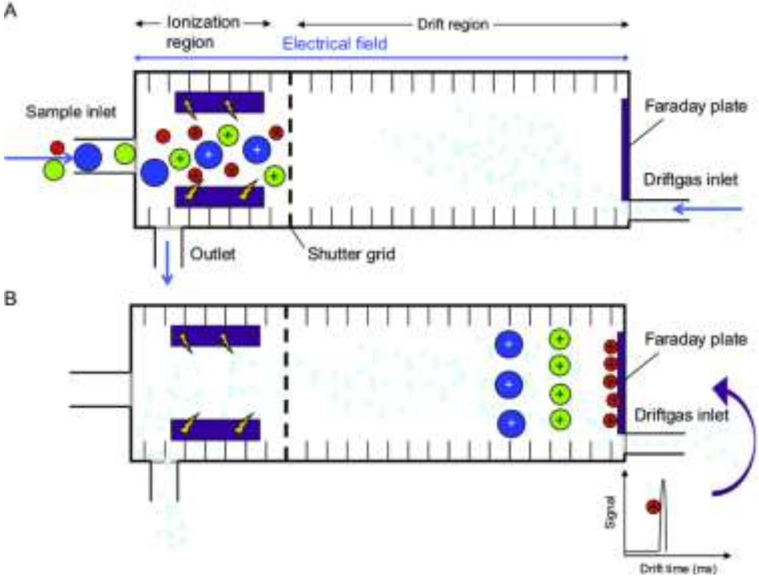

Figure 1. IMS working scheme (Arce & Valcarcel, 2013)

Portable Detection Device Capabilities and Features

Widely used in military and civilian settings, portable IMS devices like the ChemProX and LCD 3.3 are equipped with advanced operational features designed to enhance detection effectiveness in the field, particularly under hazardous conditions. These devices have multi-target detection capabilities, enabling them to simultaneously detect and differentiate between various chemical compounds, including toxic industrial gases and hazardous chemical agents. Furthermore, these devices are equipped with an early warning system with visual, audible, and vibration alarms that can be adjusted according to the level of danger detected. Connectivity features like Bluetooth, GPS, and wireless reporting capabilities to a command center enable real-time data transmission, supporting rapid and coordinated decision-making. In terms of durability, these devices are designed with IP67 certification, making them water and dust resistant and capable of operating in extreme temperatures—making them ideal for use in chemical disaster response settings.

This combination of features makes IMS devices highly effective for use in complex operational environments, such as areas with low lighting, poor ventilation, or potential cross-contamination. Modern IMS systems are crucial tools in the rapid assessment of chemical threats due to their sensitivity, portability, and adaptability to a variety of tactical scenarios. This is further supported by guidance from the US Department of Homeland Security (2018), which emphasizes the importance of integrated sensor systems such as IMS in strengthening national preparedness against chemical, biological, radiological, and nuclear (CBRN) threats.

Figure 2. Chempro-X Chemical Detection Equipment With IMS Technology

Relevance in Disaster Response Scheme

The integration of Ion Mobility Spectrometry (IMS)-based gas detection devices into field operations can directly strengthen various key functions within the Incident Command System (ICS) framework. One of its key contributions is the early identification and characterization of hazard zones (Hot Zones), which allows response teams to quickly delimit contaminated areas, thereby minimizing the spread of exposure. Furthermore, these devices provide data-driven decision-making support, where real-time, scientifically validated detection results can be used before evacuation or decontamination, ensuring that every step taken is appropriate and efficient. From a personnel safety perspective, IMS functions as an early warning system that provides alarms for the presence of toxic gases, allowing field personnel to avoid hazardous areas. Equally important, through GPS integration, detection data can be combined with tactical mapping systems to produce spatial contamination maps, which are highly useful in developing response and logistics strategies. The combination of these four functions makes IMS a critical component in a chemical disaster command and control system.

The use of this technology also enables real-time reporting to the control center, facilitating efficient inter-unit coordination and accelerating strategic decision-making. In addition to field capabilities, modern IMS devices are equipped with wireless digital data integration features, such as Bluetooth, Wi-Fi, and Global Positioning System (GPS). This allows for direct transmission of detection data to the command center, either through a situational dashboard or a GIS-based disaster information system application. Through this connectivity, contaminant concentration data, location coordinates, and detection time can be visualized spatially on a dynamic map, facilitating real-time monitoring of exposure zones (real-time plume mapping).

Furthermore, IMS data can be linked to Decision Support Systems (DSS) and digital command platforms such as WebEOC or SIREM used by disaster agencies. Integrating IMS devices into emergency response systems plays a crucial role in accelerating the information cycle required for chemical disaster management. This process begins with the detection phase, where IMS devices identify the presence and type of hazardous chemical compounds in real time. The detection results then enter the validation phase, which involves checking and confirming the accuracy of field data by officers or through an algorithm-based system. Next, the validated information is processed in the visualization phase, which involves spatial mapping through integration with a geographic information system (GIS) or a tactical dashboard at the command center. This visualized information forms the basis for the command-issuing phase, which involves strategic decision-making by field command. Finally, the entire process leads to the response phase, which involves implementing technical measures such as evacuation, decontamination, or locking down affected areas. With IMS integrated into this chain, the response system becomes more adaptive, faster, and based on real-time data. This digital integration not only increases the speed of response, but also minimizes communication errors between units, and ensures precise cross-sector coordination in multidimensional crisis conditions.

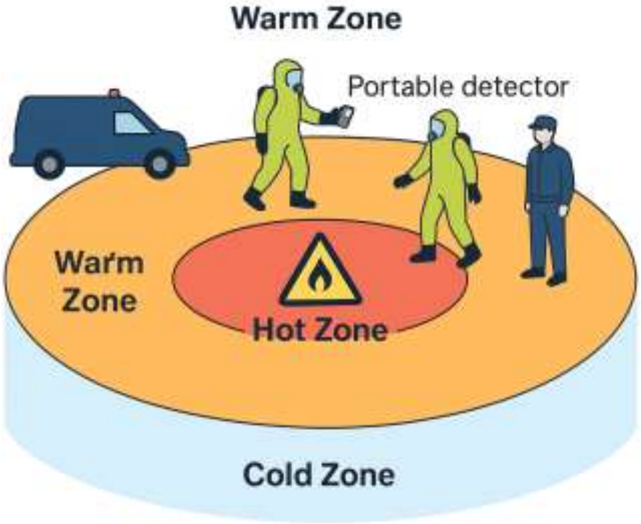

Figure 3. Placement of Portable Detectors in handling disaster threats (edited by the author)

Figure 3 shows the placement of portable gas detection devices based on Ion Mobility Spectrometry (IMS) according to the zone divisions in the CBRN emergency response system, which consist of the Hot Zone, Warm Zone, and Cold Zone. The Hot Zone is the core area of contamination where the risk of chemical exposure is highest. In this zone, detection devices are carefully used to identify the type of contaminant and the danger zone boundary. The Warm Zone serves as a transition area and decontamination location, where detection devices are used to verify residual exposure in personnel or objects exiting the Hot Zone. Meanwhile, the Cold Zone serves as a safe area and command center, where detection data is received in real time to support analysis and decision-making. The strategic placement of detection devices in these three zones allows for comprehensive contamination mapping, optimal protection of personnel, and tactical responses based on direct data from the field.

Implementation Challenges

Despite its great potential in supporting rapid response to chemical disasters, the widespread implementation of Ion Mobility Spectrometry (IMS)-based gas detection technology still faces challenges.a number ofsignificant challenges. One major obstacle is the limited number of detection units, with devices not being evenly distributed across all KBRN units and high-risk areas, such as chemical industrial areas. Furthermore, the implementation of this technology relies heavily on specific training, as it requires a thorough understanding of IMS spectrum interpretation, calibration procedures, and device maintenance to maintain detection accuracy.

Another challenge is the lack of national standardization for integrating IMS devices into emergency response standard operating procedures (SOPs), resulting in less than optimal and coordinated field utilization. Furthermore, IMS devices require regular maintenance and testing to ensure precise detection performance, including replacement of sensor components and validation of system functionality. Therefore, to ensure long-term effectiveness, institutional capacity building is needed through the development of national regulations related to gas detection system standardization and the allocation of a dedicated budget for device procurement and ongoing field personnel training.

CONCLUSION AND RECOMMENDATION

The integration of Ion Mobility Spectrometry (IMS)-based gas detection technology into chemical disaster emergency response systems has been shown to significantly contribute to the speed, accuracy, and effectiveness of field response. Portable IMS devices such as ChemProX and LCD 3.3 are capable of detecting a wide range of toxic compounds simultaneously, in real time, and under complex field conditions. This advantage directly supports strategic functions within the Incident Command System (ICS) structure, such as hazard zone identification, personnel protection, and data-driven decision-making.

Furthermore, the IMS's ability to integrate with digital reporting systems and spatial maps accelerates the information cycle, from detection, validation, visualization, to response implementation. However, the use of this technology still faces challenges in terms of device distribution, the need for technical training, and the lack of a national standard for integration into disaster management standard operating procedures (SOPs).

Thus, this study emphasizes the importance of systematic adoption of gas detection technology within the framework of national preparedness. Efforts to increase institutional capacity, allocate dedicated budgets, and provide technical regulations that support the standardization and interoperability of gas detectors across all disaster response units are urgent steps to address the increasingly complex threat of chemical disasters.

This study is limited by its methodological approach, which relies solely on literature and lacks empirical field data such as case studies or user interviews. Furthermore, no direct trials have been conducted on the integration of IMS devices into national-scale disaster simulations. For future research, it is recommended to conduct quantitative evaluations of the effectiveness of IMS responses through field simulations or real-time data from task forces. Future research should also explore the integration of IMS with AI and machine learning technologies to predict contaminant spread patterns and optimize early warning systems.

ADVANCED RESEARCH

Future research can advance the integration of Ion Mobility Spectrometry (IMS) by developing an AI-assisted IMS network system connected to national disaster dashboards. This innovation would enable real-time predictive modeling of toxic gas dispersion using machine learning algorithms trained on historical chemical incident data. Additionally, longitudinal field studies involving simulations with KBRN units in industrial zones can empirically measure the operational impact of IMS deployment on detection speed, coordination efficiency, and responder safety. The research can also evaluate the economic feasibility of scaling IMS coverage nationwide, identifying optimal device allocation strategies, training curricula, and maintenance frameworks tailored for disaster-prone regions in developing countries like Indonesia.

REFERENCES

Ahrens, A., Allers, M., Bock, H., Hitzemann, M., Ficks, A., & Zimmermann, S. (2022a). Detection of Chemical Warfare Agents with a Miniaturized High-Performance Drift Tube Ion Mobility Spectrometer Using High-Energetic Photons for Ionization. *Analytical Chemistry*, *94*(44), 15440–15447. https://doi.org/10.1021/ACS.ANALCHEM.2C03422

Ahrens, A., Allers, M., Bock, H., Hitzemann, M., Ficks, A., & Zimmermann, S. (2022b). Detection of Chemical Warfare Agents with a Miniaturized High-Performance Drift Tube Ion Mobility Spectrometer Using High-Energetic Photons for Ionization. *Analytical Chemistry*, *94*(44), 15440–15447. https://doi.org/10.1021/ACS.ANALCHEM.2C03422/ASSET/IMAGES/LARGE/AC2C03422_0007.JPEG

Ahrens, A., & Zimmermann, S. (2021). Towards a hand-held, fast, and sensitive gas chromatograph-ion mobility spectrometer for detecting volatile compounds. *Analytical and Bioanalytical Chemistry*, *413*(4), 1009–1016. https://doi.org/10.1007/S00216-020-03059-9/TABLES/2

Arce, L., & Valcarcel, M. (2013). The Role of Ion Mobility Spectrometry to Support the Food Protected Designation of Origin. *Comprehensive Analytical Chemistry*, *60*, 221–249. https://doi.org/10.1016/B978-0-444-59562-1.00009-8

Chen, C., Reniers, G., & Khakzad, N. (2021). A dynamic multi-agent approach for modeling the evolution of multi-hazard accident scenarios in chemical plants. *Reliability Engineering & System Safety*, *207*, 107349. https://doi.org/10.1016/J.RESS.2020.107349

Cumeras, R., Figueras, E., Davis, C. E., Baumbach, J. I., & Gràcia, I. (2015). Review on Ion Mobility Spectrometry. Part 1: Current Instrumentation. *The Analyst*, *140*(5), 1376. https://doi.org/10.1039/C4AN01100G

Departement of Homeland Security, D., Directorate, T., Security Enterprise, H., & Responders Group, F. (n.d.). *Ion Mobility Spectrometers -- Project Highlight*. Retrieved June 17, 2025, from https://www.rkb.us/saver

Detection, M., & Locations, I. (2021). *and Volatile Chemicals in Laboratories and Industrial Locations*.

Dodds, J. N., & Baker, E. S. (2019a). Ion Mobility Spectrometry: Fundamental Concepts, Instrumentation, Applications, and the Road Ahead. *Journal of the American Society for Mass Spectrometry*, *30*(11), 2185–2195.

https://doi.org/10.1007/S13361-019-02288-2/ASSET/IMAGES/MEDIUM/JS8B06240_0005.PNG

Dodds, J. N., & Baker, E. S. (2019b). Ion Mobility Spectrometry: Fundamental Concepts, Instrumentation, Applications, and the Road Ahead. *Journal of the American Society for Mass Spectrometry*, *30*(11), 2185. https://doi.org/10.1007/S13361-019-02288-2

Haley, L. V., & Romeskie, J. M. (1998). GC-IMS: a technology for many applications. *Enforcement and Security Technologies*, *3575*, 375–383. https://doi.org/10.1117/12.335012

Joshi, M. (2024). Ion Mobility Spectrometry in Forensic Science. *Encyclopedia of Analytical Chemistry*, 1–17. https://doi.org/10.1002/9780470027318.A1113.PUB3

Kujawińska, A., & Vogt, K. (2015). Human factors in visual quality control. *Management and Production Engineering Review*, *6*(2), 25–31. https://doi.org/10.1515/MPER-2015-0013

Lippin, T. M., McQuiston, T. H., Bradley-Bull, K., Burns-Johnson, T., Cook, L., Gill, M. L., Howard, D., Seymour, T. A., Stephens, D., & Williams, B. K. (2006a). Chemical plants remain vulnerable to terrorists: A call to action. *Environmental Health Perspectives*, *114*(9), 1307–1311. https://doi.org/10.1289/ehp.8762

Lippin, T. M., McQuiston, T. H., Bradley-Bull, K., Burns-Johnson, T., Cook, L., Gill, M. L., Howard, D., Seymour, T. A., Stephens, D., & Williams, B. K. (2006b). Chemical plants remain vulnerable to terrorists: A call to action. *Environmental Health Perspectives*, *114*(9), 1307–1311. https://doi.org/10.1289/EHP.8762/ASSET/3B56050F-C23C-41A7-889A-743107A93F2B/ASSETS/GRAPHIC/EHP0114-001307F1.JPG

Lyu, J., Zhou, S., Liu, J., & Jiang, B. (2023a). Intelligent-Technology-Empowered Active Emergency Command Strategy for Urban Hazardous Chemical Disaster Management. *Sustainability (Switzerland)*, *15*(19). https://doi.org/10.3390/SU151914369

Lyu, J., Zhou, S., Liu, J., & Jiang, B. (2023b). Intelligent-Technology-Empowered Active Emergency Command Strategy for Urban Hazardous Chemical Disaster Management. *Sustainability 2023, Vol. 15, Page 14369*, *15*(19), 14369. https://doi.org/10.3390/SU151914369

Lyu, J., Zhou, S., Liu, J., & Jiang, B. (2023c). Intelligent-Technology-Empowered Active Emergency Command Strategy for Urban Hazardous Chemical Disaster Management. *Sustainability 2023, Vol. 15, Page 14369*, *15*(19), 14369. https://doi.org/10.3390/SU151914369

Masekela, R., Zurba, L., & Gray, D. (2018). Dealing with Access to Spirometry in Africa: A Commentary on Challenges and Solutions. *International Journal of Environmental Research and Public Health, 16*(1), 62. https://doi.org/10.3390/IJERPH16010062

Reed, D., Gooding, R., Fox, S., Morton, D., & Cox, J. A. (2019). *Assessing the Risk from Stolen or Diverted Toxic Industrial Chemicals*.

Yu, K., Liu, P., Zhou, L., & Feng, R. (2024). Research on Integration of Safety Policy System in Petrochemical Enterprises Based on Risk Hierarchical Control and Hidden Danger Investigation. *Sustainability (Switzerland), 16*(20). https://doi.org/10.3390/SU16208746