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Chemical Terrorism and Forensic Science: Current Scenario and Future Strategies to Tackle Terrorism

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ABSTRACT: Chemical agents were first used, in war, by the Germans and French. These are hazardous substances, administered mainly via inhalation and oral routes, distributed in the body, and produce adverse effects on the human body according to particular properties. Such attacks are carried out on large scales and in an open environment. Detecting chemical agents and categorizing attacks as accident or terrorism is challenging. After 1970, in chemical terrorism, >30.5% and >11.6% of incidents involve unknown chemicals and gases respectively. Terrorism is mainly countered by the government and military, but forensic techniques are required for the analysis of evidence, and chemical agents; and to provide information for further investigations. Forensic analytical tools like spectroscopy, mass spectrometry, and chromatography are majorly used for the detection of chemical terrorism agents. Still, new tools with more specificity and sensitivity are required to counter terrorism and minimize threats to human life.

Keywords: Analytical Tools, Chemical Terrorism, Chemical Warfare Agents, Forensic Science, Terrorism.

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INTRODUCTION

Chemical terrorism is a subset of terrorism and is associated with the intentional release of hazardous or biochemical substances, to terrorize large groups of individuals due to the impact of the poisonous effects. It is also a form of ignoring rules, combining often the worst means of murder. The main conclusions are related to the large potential of the terrorists to use such materials to produce significant effects in populated areas. Despite the existence of other means like conventional explosives or firearms, the concept of this kind of terrorism goes beyond the criminal aspect. It also refers to its potential panic effects. Chemical terrorism is not a new phenomenon, being used in the 20th century not only in war but also in civil conflict; it was used to kill people because of political reasons. Now an old weapon of war has come down to an assassination weapon.[1, 2] Chemical terrorist attacks have an immediate impact on human life. These are relatively easy to make and use and can create fear. Chemicals used for this purpose produce rapid, nonspecific symptoms, syndromes, and clinical illnesses. The acute onset of lungs, eyes, or skin damage can be produced with the use of chemical agents. Even though most of these agents may not be tangible, a scare could result, causing mass panic and potentially overwhelming the public health infrastructure. A good number of these agents are not yet identified.[3] In medieval times there was a concept of poisoning wells and food stocks in the cities, but there were hardly any well-documented cases of chemical terrorism until the early last century.

The reason may be that poisons like arsenic or cyanide which would poison slowly could not cause much panic nor could simple methods of chemical protection like boiling water and other simple cooking methods destroy their toxicity. Thus, it is with the advent of chemical agents with the ability to cause panic that chemical terrorism actions were seen.[4, 5] The first well-documented incident of the use of chemical agents in World War I was when the German troops released chlorine gas for the first time, with the most dramatic military consequences. However, both sides avoid using chemicals as weapons for the rest of the conflict. After the Versailles Treaty, the German scientists refrained from further development of chemical weapons. However, in the Far East countries, the rising numbers of guerrillas resulted in the first non-military use of chemicals in the form of assassinations and large-scale murders being carried out. Many of the compounds used in these had been banned earlier for use in war conditions.[5, 7] According to the Global Terrorism Database (GTD), there were more than 400 terrorist activities that involved the use of chemical agents (Figure 1). Significant incidents have been reported in Afghanistan, Iraq, and Japan. Attacks often involve unknown chemicals, with certain nations experiencing a higher frequency of unidentified substances. Noteworthy chemicals detected include explosives, incendiaries, and biological agents. The targets of these attacks are diverse, frequently encompassing private individuals, educational establishments, and government buildings. Countries such as the United States and Russia have also shown instances of biological chemicals in some situations. The overall occurrence and consequences of chemical terrorism vary by country, with some areas demonstrating a higher rate of these events compared to others (Table 1).[6]

RESULT

Table 1. Chemical Terrorism in different countries between 1970-2020.

Country	Total No. of Incidents	% of cases where the unknown chemical is used	Total % of Chemical Terrorism
Afghanistan	50	25%	15%
Albania	01	0%	1%
Angola	10	40%	8%
Argentina	05	15%	10%
Australia	15	10%	05%
Bangladesh	08	05%	03%
Belgium	12	25%	08%
Brazil	09	30%	10%
Bulgaria	02	20%	02%
Cambodia	01	05%	01%
Canada	07	15%	06%
Chile	06	10%	04%
China	03	05%	03%
Colombia	20	40%	15%
Congo	03	0%	02%
France	14	20%	08%
Germany	25	25%	15%
India	40	50%	25%
Iraq	18	15%	10%
Italy	08	05%	06%
Japan	30	10%	20%
Jordan	05	40%	10%
Libya	02	0%	02%
Mexico	01	10%	01%
New Zealand	04	05%	02%
Nigeria	06	30%	15%
Palestine (West Bank and Gaza Strip)	08	40%	10%
Pakistan	12	10%	05%
Peru	03	20%	10%
Philippines	15	30%	20%
Russia	05	25%	04%
South Africa	02	10%	08%
Sri Lanka	20	05%	02%

Sweden	20	30%	08%
Syria	04	20%	15%
Tanzania	03	15%	03%
Ukraine	50	25%	25%
United Kingdom	04	30%	03%
United States	03	15%	03%
Venezuela	10	20%	08%
Vietnam	03	15%	03%

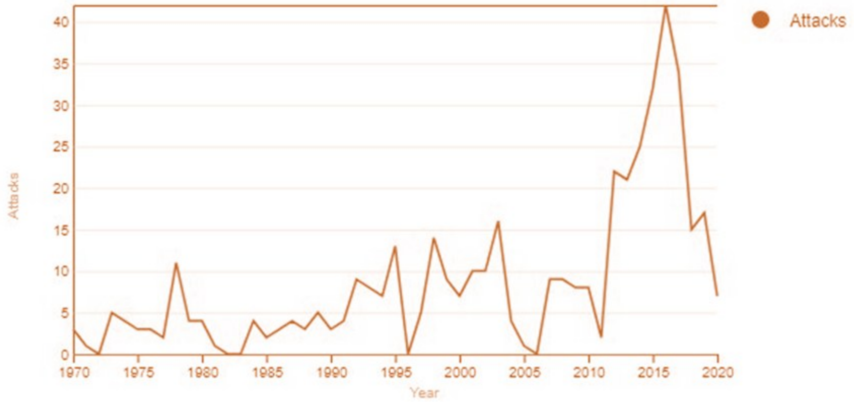

Figure 1: Line chart showing the No. of attacks involving chemical agents over 50 years.

Types of Chemical Agents

Nerve Agents

Nerve agents, including organophosphates, are chemicals that cause signs and symptoms of toxicity. These act by inhibiting the normal functioning of acetylcholinesterase, an enzyme needed at nerve endings to control many systems such as breathing and glandular action. Nerve agents are some of the most lethal and rapidly acting toxic chemicals. Other potent organophosphates used as nerve agents include soman, sarin, and V-agent. Acetylcholine is a neurotransmitter in humans and other higher animals that stimulates the transmission of nerve signals across synapses and at neuromuscular junctions. Stimulation of muscarinic postsynaptic receptors at several target organs occurs by acetylcholine released from most postganglionic nerve endings. These compounds irreversibly inhibit acetylcholinesterase and other cholinesterases. Nerve agents appear to age the anticholinesterase moiety by reacting with and displacing the alkyl phosphyl group on the enzyme. Effective nerve agent antidotal therapy is still a subject of investigation. At present, first-aid nerve agent antidotes consist of the combined administration of 120 mg atropine and 2g 2-PAM chloride.[8]

Blister Agents

Blister agents, also known as vesicants, are a group of chemicals that have chemical properties similar to those of mustard gas. They act as cutting agents that injure the tissues of the body. These include both sulfur mustard and nitrogen mustard. Their vapors are heavier than air and may induce asphyxiation in confined and poorly ventilated spaces. They are severe irritants of the skin, eyes, and respiratory tract. Exposure to large concentrations vapor, of sulfur mustard, can result in serious injury or death. Sulfur mustard is a persistent material that can remain on surfaces for days to weeks. It can access the body through inhalation, ingestion, and skin contact.[9] The German military in World War I first used Sulfur mustard. It was the most feared chemical weapon agent during that war and was labeled as The King of the Battle Gases.[10] Production of these agents and their weapons is forbidden under the Chemical Weapons Convention of 1993. Sulfur and nitrogen mustards are named for their offensive smell and not for their structure. These compounds do not possess a mustard seed odor. They have a very minor or non-existing odor, respectively. These compounds are not true gases but are a family of related classes of the separate chlorination products of the parent molecules. Each member of the family has a different vapor pressure threshold.

Blood agents

Blood agents including hydrogen cyanide and cyanogen chloride (cyanogen-type chemicals) are toxic substances that disrupt cellular respiration. These agents interfere with the enzyme cytochrome oxidase inhibiting the cell's ability to use oxygen. This results in internal suffocation, where tissues and organs are deprived of oxygen despite its presence in the bloodstream.[11] Blood agent poisoning symptoms include dizziness, rapid breathing, headache, and confusion, which can lead to seizures, coma, and even death if the concentration is high or exposure is prolonged. These agents, sometimes, cause fatalities within minutes making them extremely dangerous in incidents involving mass exposure. Hydrogen cyanide was considered for military use due to its effectiveness in closed environments. However, blood agents are highly volatile and disperse quickly, limiting their effectiveness outdoors.[11] Blood agents, due to their potency, have been used in several terrorist attacks often released in confined spaces to maximize harm. They have also found illicit use in assassinations due to their ability to cause instant and hard-to-trace fatalities. This makes blood agents an insidious tool in chemical terrorism and emphasizes the importance of rapid response and decontamination measures when dealing with such incidents.

Choking Agents

Choking agents such as chlorine gas and phosgene primarily target the respiratory system by damaging lung tissue and causing inflammation and fluid buildup. Inhalation irritates the lining of the respiratory tract resulting in coughing, chest pain, and difficulty breathing. Chlorine, known for its use in World War I, reacts with water in the lungs to form hydrochloric acid resulting in chemical burns and damages the lung tissues. Phosgene is even more dangerous due to its delayed effects where symptoms may not appear for several hours after exposure and leads to respiratory distress and potential fatal pulmonary edema.[12] The delayed action of agents like phosgene makes them particularly challenging in emergency response scenarios, as individuals may initially seem unaffected but experience severe symptoms hours later. Due to their high reactivity choking agents are less commonly used in open warfare today but remain a threat in enclosed spaces or during targeted attacks in populated areas.[13] Protective measures include masks and enclosed suits but rapid medical intervention is critical for exposed individuals. Due to their devastating impact on the lungs these agents serve as a reminder of the need for international agreements, like the CWC, to prevent the use of such weapons in conflicts.

Irritants

Irritants commonly stated as riot control agents, are less lethal but are used to cause temporary discomfort and incapacitation. Common examples include tear gas (CS gas) and pepper spray which target the eyes, skin, and respiratory system, causing symptoms like tearing, burning, coughing, and respiratory distress.[14] While these agents are generally intended for crowd control and are considered non-lethal, high doses or prolonged exposure can lead to more serious respiratory problems and in extreme cases, death. Tear gas is particularly dangerous in confined spaces as the buildup of the agent can cause severe reactions. These agents are widely used by law enforcement and military forces worldwide in controlling riot and crowd dispersal. Even if they are less dangerous than other chemical agents the effects can still be traumatic for elderly people, children, and those with respiratory conditions.[15] The use of irritants in warfare is banned under the CWC but their application in domestic law enforcement remains a subject of debate as prolonged exposure has raised questions about potential health risks.

Incapacitants

Incapacitants are designed to disable rather than kill. It targets the central nervous system and causes confusion, fatigue, and muscle weakness. A well-known incapacitating agent is BZ (3-quinuclidinyl benzilate) which affects cognitive and motor functions leaving individuals disoriented, lethargic, and unable to perform coordinated movements.[16] These agents are often chosen for their ability to incapacitate without causing lasting physical harm however the psychological effects can be significant.The primary challenge with Incapacitants lies in dose control as prolonged exposure can lead to severe incapacitation. Incapacitants are less lethal than traditional chemical agents, their use raises ethical questions as they can strip individuals of autonomy and make them vulnerable to harm. Military interest in such agents remains as they offer a way to disable opponents temporarily without resorting to lethal force.[16]

Lethal Pulmonary Agents

Lethal pulmonary agents are potent chemicals that cause severe and often fatal damage to the respiratory system. These include diphosgene and perfluoro isobutylene which target lung tissue causing fluid accumulation and hemorrhaging. These agents are designed to disturb lung function leading to rapid respiratory failure. Exposure to lethal pulmonary agents results in difficulty breathing, chest pain, and blood-tinged coughs; with death following shortly after exposure in high concentrations.[17] Lethal pulmonary agents are dangerous due to their potency and rapid effects making them perfect for closed-space deployment where the agent concentration can remain high. While less commonly discussed than other chemical agents they represent a significant threat in confined spaces and could cause catastrophic harm in populated areas. The damage to lung tissue is often irreversible stressing the critical need for protective measures and rapid medical intervention to counteract their lethal effects.[17]

Delivery Methods of Chemical Agents in Chemical Terrorism

Delivery methods that terrorist groups may prefer to use to attack by chemical agents are important for developing countermeasures, predicting the course of events, and estimating the potential damage. Characteristics of the chemical agents to be used will be the main determinants for selecting those methods. Unlike traditional military chemical agents, the chemical agents used in the context of terrorism are not likely to be dispersed over a large area and for duration in combat. A delivery method that is rapid and efficient in delivery to the target population without environmental contamination is preferred.[18-20]

Aerosolization

An inhalable aerosol is used due to the high lethality associated with some of these agents, ease of transport of an inhalable form, negligible requirements for purification, and direct interaction with the target.[19] The main factors that enhance the risk of public exposure to hazardous chemical agents are their volatility, persistence, and easy accessibility of the chemical agent. The exposure dose is also linked to nature and the volume of the delivered agent. The factor that determines the risk of hazardous substances is the concentration of the harmful agents in the environment. In general, gaseous materials are rapidly diluted in the atmosphere and the presence of chemical vapor depends on the nature of the substance, its volatility, and the organism's exposure time. Volatilization can facilitate transmission among people since it can allow the contamination of the interior and exterior of buildings and vehicles.[21]

Water Contamination

Water as a delivery method for chemical agents attempts to poison a target through water contamination. This is carried out as direct contamination of the water source line or reservoir. Isolated municipal systems can also be used for delivery, such as by poisoning the main intakes to large urban reservoirs from a boat on the water itself. Still, these methods are relatively easy to guard against, recognize, and respond to. With present-day security and monitoring systems, there are very few feasible methods for introducing a chemical warfare agent (CWA) into a water supply without detection. A few agents are sufficiently toxic to inactivate large-scale treatment with standard municipal water purification systems, and some agents could not be removed in sufficient concentration at any level, depth, or distance of water treatment.[22]

Food Contamination

Food materials are potentially good targets for a chemical terrorist attack. The impact of such an act could be tremendous because it is not only people who are affected but also the image of a region or a country, and their products will be damaged. In many countries, the agriculture industry is a major portion of the economic structure. If a terrorist gained access to a food preparation plant, they could introduce a harmful chemical to the product. Then they will package the product and distribute it. Exported food could also be a target. The delivery method can be a mixing bowl, a conveyor belt, or a distribution system.[23] Countries have had previous experiences, in Japan, a religious cult attempted to release botulinum toxins through fresh food. The total number of cases reached 1004, with 3 deaths and at least 13 different illnesses. More than 5,500 went to hospitals for complaints with initial symptoms of nausea. The agents include Staphylococcus aureus and Vibrio cholerae, potentially leading to death.[24, 25]

Forensic Analysis of Chemical Agents

The first respondents to terrorist attacks are mainly military, law enforcement, and government. The primary responsibility lies with government authorities possessing intelligence information. However, the forensic laboratory analyzes any evidence developed—the size, shape, and color of a suspect package, trigger mechanism or point of origin, and use of electronic or written communication. Chemical agents, used in terrorism, of forensic interest are toxic compounds that are less likely to be encountered in everyday experience and may be otherwise used for hostile purposes. That is why forensic areas such as action preservation, moderate environment, separation and detection, toxicological analysis, and their effective personnel protection in use become particularly important. The main goal of forensic work in the field of chemical terrorism is the chemical identification and attribution of samples to their source from the available data. Specific approaches make use, from the practical point of view, of modern sophisticated analytical technologies and computational tools for chemical structure modeling and mechanism research. Apart from the primarily forensic information stage, based on the modern physicochemical and toxicological data of the most common chemical agents, such as organophosphorus and organic carbonyl compounds, the main forensic analytical steps are considered that lead from the sampling strategy to the evaluation of the analytical data. As a result, a reliable expert conclusion is provided on the nature of the real agent, the assessment of environmental risks that may evolve from the contamination, and the specification of the necessary personal protective equipment for use by the investigation teams.[26]

Analytical Techniques for Chemical Agent Detection

Chemical agents are compounds developed specifically to cause injury or death when introduced by any of the approved routes, be it skin contact, ingestion, or inhalation. In response, all of the detection technologies focus on ensuring trace compatibility. The technology is based mainly on analytical technologies whose objective is to concentrate and make available to the agent detector the highest possible amount of sample for analysis. However, not all chemical agent detection technologies are based on analytical techniques. Multiple other physical and antibody methods adapt to similar purposes of detecting chemical agents in the case of a terrorist attack. The optimization of laboratory conditions is of great importance in the analysis of micro-traces of chemical agents.[27] In the case of a chemical agent, the strategy is the opposite. The large action mechanisms that work with chemical agents are in Parts Per Million (PPM) or Parts Per Billion (PPB), and their detection technology must have a huge specificity adjustment for the chemical compound researched. Direct detection of chemical agents in the field is performed by a type of gold catalyst that releases volatile organic compounds from chemical agent compounds in the presence of chloride and mustard agents. Detection is performed by a spectrophotometer or flame photometer after pore balls are prepared with gold alloys. Particle counts are taken at the moment of precipitate formation when chloride salts decompose violently. Before encapsulation, the technique reduces the lethal response of the precipitation.[28]

Spectroscopic Techniques

Infrared (IR) and Raman spectroscopies have been widely used for the detection of chemical terrorism agents at even very low vapor pressures in real-time in the gas phase through open path techniques. In the open-path technique, IR sources such as incandescent and laser radiation which emit in the mid-IR region, and broadband detecting devices are necessary. The gas phase compounds absorb radiation at characteristic frequencies related to bond stretching and are detected through optical means, allowing the detection of large parts of the spectrum from one stationary point. However, complicated experimental apparatus makes this technique expensive.[29] ATR (Attenuated Total Reflection) devices have been used for the detection of nerve gases in the solid and condensed phases. Some researchers have proposed new portable devices for Surface Acoustic Waves (SAW) sensors and spectrophones. The SAW sensors detect the mechanical transduction between a surface acoustic wave and the vapor phase of chemicals that are adsorbed on the polymeric waveguide made of nitrile groups. The main drawback is low sensitivity and the difficult discrimination between interfering analogues. The spectrophone is a Light-emitting electrochemical cell that works with a Fabry-Perot laser diode. The light beam is reflected back and forth between two mirrors and interacts with the analytes, transforming the electrically excited current into a sono-acoustic wave. The wave is finally detected close to the photodiode by a piezoelectric transducer and processed. This spectrophone device has been applied to the detection of nerve agents in the gas phase, and it is projected for application in the liquid and solid phases. High sensitivity is a feature of the method.[30, 31]

Chromatographic Techniques

Chromatographic techniques can use different mechanisms, formats, adsorbent materials, and analytical coupling. Gas chromatography provides a high-efficiency separation in combination with a wide variety of detection systems and can engage headspace or thermal desorption samplers. These latter procedures require little to no sample treatment, while headspace samplers can be used in grab or dynamic air monitoring. The main limitation is that the approach is laborious and time-consuming due to the apparent lack of compact fast gas chromatographs. High-pressure or micro-carry auxiliary components for the multi-column approach, small-bore analytical columns, or relatively new preconcentration and chromatographic separation concepts allow the shortening of the analysis time, but achieving a sub-minute evaluation remains challenging. Silicone-based materials and gas chromatographic well-adapted detectors provide specific, sensitive, and selective detection of persistent nerve agents in air monitoring.[32]

Mass Spectrometry

Mass spectrometry combines the features of a non-separated analytical technology and a universal detector and is in a position to provide much information on the chemical composition of complex samples. The most important characteristic of mass spectrometry is the ability to identify a particular chemical compound uniquely, primarily based on the mass number of its ions. Electron ionization sources of mass spectrometers have a much higher sensitivity to most CWA than gas chromatography detection since much larger proportions of the sample are present in the ion source of the mass spectrometer. Mass spectrometry, coupled with gas or liquid chromatography, has been extensively used to obtain increased detectivity in solving analytical problems related to chemical weapons and chemical terrorism. Generally, tandem mass spectrometry provides high selectivity by combining two stages of mass spectrometric analysis: a first mass analyzer is used to isolate and fragment precursor ions of a specific m/z value, and then a second mass analyzer is used to detect the fragment ions. The excessive chemical specificity of mass spectrometry is frequently a valuable asset in the identification of unknown samples. Mass spectrometry is, in many cases, ideally suited for on-site measurements because of (a) perhaps the highest sensitivity of any instrumental technique; (b) the simplicity of the necessary sample handling procedures; and (c) the small amount of sample required for analysis.[33]

Challenges in Investigating Chemical Terrorism

Although much progress has been made in studying the toxic effects of chemicals for protective and diagnostic purposes, many areas of investigation are similar to pharmaceutical research and development. Conducting this research with toxic chemical agents is considerably more complicated and faces many more substantive constraints than other areas of public health policy. The legal and regulatory barriers, along with the cost and the inherent dangers associated with the research and handling of these agents, have made the task of developing new and improved detection methods, which more than any single entity can handle. The development of these scientific and technical advances is especially onerous as the threat of terrorist use of toxic industrial chemicals, especially for mass casualty purposes, remains relatively rare and hence lacks the same level of public desirability and support as other pharmaceutical advances.[34] Another problem with developing new and improved techniques for toxic industrial chemical detection is the difficulty in recognizing the limitations of our current tools. First, detection of the agent is not easy. Second, we need simpler, faster, and cheaper tools to triage exposed populations in a crowded and busy environment, identify those who are actually at risk for moderate to severe injuries, achieve greater specificity and sensitivity with the tools we currently have, relate target agent concentrations to exposure dose and human response, and finally develop better risk communication tools that are easily understood and usable by the layperson population, especially in a stressful or crowded environment.

Detection and Identification of Chemical Agents

Detection of chemical agents is the priority in a terrorism incident. Due to the broad range of chemical agents that could potentially be used by terrorists and the various methods for dissemination, both point and standoff detection is essential. Several factors exclude the possibility of using only one system for both of these approaches. An ideal network would contain an integrative sensor system using variable detection principles, covering a wide area and required accuracy. Further research should be conducted to combine sampling and analytical methods both in a detector and a network of detectors. The future development of a Chemical Terrorism Agent sensor network should be integrated into the civil contingencies planning and alerting systems of the country concerned. Such a network should be modular, with elements that could be easily removed and/or replaced.[35] The improvement of the sensitivity and selectivity of detection is an everlasting necessity. Several promising trends in sensor design could significantly enhance their detection capabilities. Over the last few decades, the fields of general analytical chemistry, environmental monitoring, investigation of biochemical processes, and others have made significant progress in development.[36] It is time to borrow some of the best developments in this specific area. The ideal analytical sensor must be capable of detecting various target compounds with high-level sensitivity and selectivity, with fast response and recovery times, operating at room temperature, and being battery-operated with a low power draw. One of the most important considerations in the practical implementation of many chemical detection systems is the sample collection procedure. The choice of analytical techniques and instrumentation is broad and diverse and includes techniques used in military laboratories such as point detectors, remote sensing instruments, and portable systems.

International Cooperation and Information Sharing

The problem of international cooperation and information sharing between the various countries, as well as between the various organizations within a given country, was addressed during the 5th Session of the Conference of the Parties to the Chemical Weapons Convention (CWC), held in The Hague in April 2002. The delegation of the U.K. stated that "the exchange of information about chemical incidents is a topical area of concern to all States Parties and is a goal on our action plan for the review conference." The delegation noted that in the thirty years since the entry into force of the CWC, "the ability of the nations of the world to respond rapidly and effectively to deal with the results of a chemical incident has advanced significantly." However, as the delegate stated, the effectiveness of decision-making and action depends upon timely access to the most recent and complete information.[37] The U.K. requested that the Organization for the Prohibition of Chemical Weapons (OPCW) provide a central place where countries can obtain and exchange information about chemical incidents, both for events that might be acts of chemical terrorism or chemical warfare and for more ordinary industrial accidents. The representative of the Netherlands mentioned that The Hague had been nominated to host the analytical laboratory and added that, in a closely related field but with a broader mandate, his country would host a new, state-of-the-art, international disaster victim identification facility, described as a real advance in the international community's joint effort to provide support in the context of major disasters.[37]

DISCUSSION

Combating chemical terrorism requires an integrated approach that spans technological advancements in detection, enhanced forensic tools, and robust cooperation. The multifaceted challenges associated with chemical detection and identification, coupled with regulatory gaps, demand collective action from scientists, policymakers, and global leaders. Through ongoing investment in research, improved information-sharing platforms, and efforts to foster international trust, the global community can better prepare to counter the threat of chemical terrorism and protect public health and safety.

Terrorists may employ a range of chemicals, from industrial toxins to specialized military-grade agents. Each type presents unique detection challenges. Advanced detection methods offer high accuracy but they are not always available in low-resource areas. Traditional detection tools may be inadequate against new, complex agents designed to evade standard identification methods. Emerging technologies such as nanomaterial-based sensors and AI-driven chemical analysis promise greater sensitivity and accuracy but require substantial investment and regulatory approval. Rapid detection kits provide immediate results and aid quick response efforts. Enhanced versions of these kits are being developed to detect a broader range of substances with greater sensitivity. Devices like portable IR and Raman spectrometers enable on-site analysis of residues without transporting samples to labs. This speeds up identification, although they are still subject to limitations in detecting all chemical types effectively. Continued investment in forensic science research will be vital to develop methods for chemical identification and trace analysis. Equipping local health agencies, first responders, and community leaders with the knowledge and resources to handle chemical incidents is critical. Public awareness campaigns can inform communities about the risks of chemical agents and effective response measures. Educational initiatives and drills could make communities more resilient to potential attacks. A unified global approach to regulating toxic industrial chemicals often readily accessible is essential. Coordinated international efforts in controlling access to these chemicals can form a defense against chemical terrorism.

CONCLUSION

This article takes the traditional law enforcement, policy, medical intervention, assessment of secondary contamination, and geopolitical concerns and lines these up to look at future research needs for the field. Posed are the remaining questions requiring answers from the medical response community to law enforcement, the importance of improved evidence collection at a Weapon of Mass Destruction (WMD) incident scene, and the geospatial modeling of uncontrolled use of chemical weapons from formal battlefields. What is demonstrated is that the current research on the subject questions in the field is no longer based only on a traditional law enforcement model, but now depends on fields like political science, geographical information systems, and governmental policy-making disciplines in an overarching fashion to come up with field-specific tests of concerns in the future. Aside from these outlined deficiencies further research should consider a range of other questions that have not yet been discussed, let alone answered. These issues run from initial response opportunities, what technologies to make available to developing nations, and the role of non-state actors in chemical weapons use to creating effective prevention strategies for the control of chemical weapons while addressing the incentives of nations to produce and use them. Heavy research programs do not exist to date in prevention, but they need to since in hindsight research on prevention could hold the key to stopping the use of chemical weapons. The future of the CWA event is something most of us agree, we would prefer not to see. Only through strong policy initiatives and programs involving stakeholders, we can hope to realize a future of preventing the severe use of a chemical weapon.

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