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Management of Chemical Terrorism and Chemical Disasters

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Abstract

Though the possibility of terrorist groups obtaining chemical weapons and inflicting mass destruction is relatively low, the relevance of chemical agents remains high since the use of such chemical agents in causing potentially dangerous consequences remains very high. Sporadic chemical attacks and chemical disasters happen all over the world, and they cause long-lasting damages. Easy accessibility to various toxic industrial chemicals and the relatively simple know-how needed to synthesize chemical agents pose a serious threat. However, technological developments and the easy availability of information have empowered the security forces and law enforcement agencies to formulate a responsive mechanism to mitigate the ill effects of chemical disasters. Though the international and national agencies strive hard to ward off the debilitating effects of chemical agents and disasters, such efforts' capability to address the potential risks remains doubtful. This review describes the characteristics and classification of chemical agents and toxic industrial chemicals, their physicochemical properties, detection, decontamination, and response by the security agencies and first responders in addressing the threat to humanity in the form of chemical terrorism and chemical disasters.

Keywords: chemical disasters; chemical terrorism; nerve agents; blistering agents; response.

Introduction

The current world's peace and tranquility are often disturbed by the chemical, biological, radiological, nuclear, and explosives (CBRNE) threat spectrum. There is an increasing trend in the convergence between terrorism and unconventional CBRNE weapons for terrorist purposes (Krstic, 2017). Many terrorist organizations operating in Syria, Iraq, Turkey, Afghanistan, and Russia use hazardous chemical substances as a tool of violence. Chemical terrorism relates to the acts of terrorism using chemical agents. It refers to the use of chemical substances and their toxic properties as weapons to inflict causalities on humanity. These chemicals are in solid, liquid, or gaseous forms, dispersed as aerosols or particles, producing lethal or incapacitating effects on humans (Aas, 2003). A large number of toxic chemicals are involved in terrorist activities. Even though chemical attacks date back to antiquity, the development of chemical weapons and munitions evolved predominantly from the world war era. In World War I, the French began using tear gas (Xylyl bromide) in grenades. It was the first significant use of chemicals in warfare. In 1915, Germans retaliated by using Chlorine gas in pressurized cylinders for the first time. Subsequently, phosgene projectiles and chlorpicrin shells were used. Phosgene turned out to be more lethal than chlorine. As the war progressed, cyanide and mustard gas were also used. After World Wars, lethal chemical agents such as Tabun, Sarin, and Soman came into use. Agent Orange and Super Orange came into use during Vietnam War. Iran-Iraq war in the 1980s was the classic example of the use of chemical weapons. Iraq also used nerve agents to attack the civilian Kurdish population (Stuart et al., 2003; Lopez-Menoz, 2008).

The main reason for using chemical weapons is that it is cost-effective and can be used at lower concentration levels. Chlorine, phosgene, and cyanides are extensively used as precursor chemicals in various chemical and pharmaceutical industries. Terrorists may target such industrial plants to release toxic chemicals and gases. The release of such agents in a closed area can kill scores of people and cause mild casualties in an open area (Ganesan et al., 2010). Chemical terrorism is a serious threat to humanity because its impact overshoots the use of advanced firearms (Patocka et al., 2004). Hazardous chemicals are getting widespread attention due to their misuse by terrorist groups in preparing 'dirty bombs' filled with gases such as chlorine, ammonia, sarin, phosphorous, mustard, hydrogen cyanide, napalm, and acidic solutions, etc. (Banks, 2015). The international community is making efforts to ban the illegal use of chemical agents. Chemical Weapons Convention (CWC) strives hard to destroy the stockpiles in an environmentally viable manner by enacting legislation. Similarly, the Organisation for Prevention of Chemical Weapons (OPCW) monitors the destruction of chemical weapons and their facilities in addition to routine inspections and verifications (CWC, 1997).

Chemical disaster denotes a catastrophe, calamity, or mishap involving hazardous chemicals in an area due to natural or man-made causes resulting in substantial loss of life and property. Such disasters happened in the past and caused lasting effects. Chernobyl nuclear reactor disaster in USSR, Bhopal union Carbide factory disaster in India on Dec. 3, 1984, due to Methyl isocyanide gas leakage, Sevaso herbicide plant accident in Italy due to leakage of 2,3, tetrachlorobenzo-10-dioxin gas, Mangalore Chemicals, and Fertilizers Ltd accident due to Ammonium carbamate leakage in a urea plant, Panipat National Fertilizers Ltd accident due to liquid ammonia burst, Flixborough explosion of cyclohexane in the UK, Beek disaster of propylene release in Netherlands, Mississagua accident due to collision of chlorine and propane laden tankers, Mexico explosion of Liquefied petroleum gas were few incidents which resulted in large scale destruction leading to degradation of the environment, damage to property and loss of life (NDMA Guidelines, 2009). High industrialization, the growth of chemical industries, and the risk associated with hazardous chemicals enhance the vulnerability of industrial chemical accidents. Chemical disasters may originate in manufacturing facilities due to technical failures or deficiencies in safety management systems and human errors during handling, storage, and transportation (Small, 2002). Human actions such as riots, conflicts, sabotage activities, and targeted industrial vandalism can also lead to chemical disasters. Natural disasters can also lead to chemical accidents. Tupras Oil refinery accident in Izmit, Turkey due to earthquake, Fukushima incident in Japan due to tsunami, Ammonia gas leakage at Oswal Chemicals and Fertilisers Ltd, Paradip due to cyclone, the release of acrylonitrile at Bhuj, due to earthquake are some of the examples of chemical disasters caused by natural calamities (Bharadwaj et al., 2007).

Chemical disasters and chemical terrorism are highly traumatic events resulting in irreparable damage to the environment and population. Such incidents result in explosions, fire, and the toxic release of obnoxious gases. Three factors are responsible for the effect and intensity of the disaster. First is the nature of chemical agents, concentration, and the period of exposure which decide the level of toxicity and damages on living organisms. Metrological parameters such as wind direction, speed, the height of the inversion layer, and persistency directly proportional to the extent of the impact of disaster are the second and the third is the location of industries or storage facilities in densely populated areas, which account for the human vulnerability. Although the frequency of chemical disaster is low, it is potential in causing immediate and long-term damages are significant (Bhawana et al., 2011).

In this paper, the characteristics and effects of the chemical agents, response to the incidence of chemical terrorism, and chemical disasters are discussed to assess the required level of safety aspects for an overall risk reduction and to formulate policies, guidelines for effective disaster management. The scientific implication of this paper is to educate the security forces and the first responders to be aware of the traits of chemicals and their effects and the means to counter them in times of exigencies.

Chemical Terrorism Agents and their Classification

Chemical agents characterize chemical terrorism, that is to say, any chemical substance, whether solid, liquid, or gas, can cause death, temporary incapacitation, or permanent injury to people, animals, and plants due to their chemical effect. Even after the Cold War, many countries and non-state actors developed and used chemical agents to inflict military and civilian casualties. Despite the efforts from various inter-governmental agencies to eradicate chemical weapons, a few technological advances have led to the development of a series of dangerous toxic warfare agents with enhanced lethal factors. A nerve agent called 'Novichok' based on carbonimidic phosphorohalide is the latest addition to the list (Nepovimova et al., 2018). OPCW prohibits the production, development, stockpiling, and transfer of chemical agents, which might pave the way for chemical terrorism.

CWC classified the toxic chemicals to cause damage under three schedules. Schedule 1 chemicals have legitimate uses and may only be used for medical and protective purposes. Production above 100 g must be reported to OPCW, and the stockpile cannot exceed one ton. These chemicals are developed, produced, and stockpiled as chemical weapons and have little or no use for permitted purposes. It falls under the high-risk category, and declaration to OPCW is necessary for each chemical produced, transferred, consumed, or stored (OPCW Declarations Handbook, 2017). Example – Nerve agents. Phosphonofluoridates (Sarin), Phosphoramidocyanidates (Tabun), Phosphonothiolates, and corresponding alkylated or protonated salts (VX) are notorious Schedule 1 chemicals.

Schedule 2 chemicals have legitimate small-scale uses and not on an industrial scale. These chemicals possess lethal or incapacitating toxicity and other properties that could be used as chemical weapons. Schedule 2 chemicals fall under the significant risk category, and declaration to OPCW is necessary for each chemical above the threshold quantities produced, processed, consumed, imported, or exported. Example – Thiodiglycol used in the production of mustard gas is used as a solvent in inks. Schedule 2 chemicals consist of toxic chemicals and precursor chemicals (OPCW Brochure, 2017). Amazon (O, O-Diethyl S-[2-diethyl amino]ethyl phosphorothioate) and corresponding alkylated or protonated salts, dialkyl phosphoramides dihalide families, N, N, dialkyl aminoethane-2-thiol families, N, N, dialkyl aminoethane-2-of families, N, N, dialkyl aminoethane-2-chloride families, pinacolyl alcohol, diphenyl - 2- hydroxyl acetic acid, Quinuclidin-3-ol, 3-Quinuclidinyl benzilate (BZ) and precursor chemicals such as chemicals containing phosphorous atom to which one methyl, ethyl or propyl groups are attached (methyl phosphoryl dichloride), comes under this schedule (OPCW, Central analytical database, 2017).

Schedule 3 chemicals have legitimate large-scale industrial uses. They may be produced, stockpiled, or used as chemical weapons as they possess lethal or incapacitating properties that might enable them to be used as chemical weapons. It falls under the moderate risk category, and declaration to OPCW is necessary if the chemical is produced, exported, or imported above threshold quantities. OPCW must be informed if any industry produces more than 30 tons per year. Chemicals such as carbonyl dichloride (phosgene), cyanogen chloride, hydrogen cyanide, trichloronitromethane (chloropicrin), and precursors such as phosphorous oxychloride, phosphorous trichloride, phosphorous pentachloride, triethanolamine, methyl diethanolamine, ethyldiethanoamine, sulfur monochloride, sulfur dichloride, thionyl chloride, dimethyl phosphite, trimethyl phosphite, triethyl phosphite etc., falls under this schedule (CWC, 1997).

The chemical agents are also classified based on their chemical nature, such as organo-phosphorous, organo-sulfur, organo-fluorine, arsenicals, and others. They are classified as lethal and incapacitating chemical agents based on their effects. On temporal effects, it is classified into persistent and non-persistent agents. Persistent denotes the presence of hazardous effects in a particular area for a longer duration, and non-persistent agents denote the absence of hazardous effects as it disperses immediately in a short period. A chemical agent is incapacitated if it is 1/100 of the lethal dose. Based on their physiological effects, they are classified as nerve agents, blistering agents, blood agents, choking agents, psychomimetic agents, riot control agents, and toxins (Hoenig, 2007).

Nerve agents

Nerve agents are man-made compounds and do not occur naturally. They are mostly liquids at room temperature with a fruity odor and belong to the organophosphates group. They have low molecular weight, low volatility, low water solubility, and high lipid solubility (Sage et al., 2004). They attack the functioning of the nervous system and are extremely harmful. Gerhard Schrader of Germany developed the first known nerve agent, Tabun (GA), as a new insecticide. Subsequently, other G-series nerve agents, Sarin (GB) and Soman (GD), were developed (Lopez-Menoz, 2008). To counter this, V-series was developed by England. VX was also developed, which is more stable, persistent, less soluble, and less volatile sulfur-containing organophosphate with an amine smell. The effect of nerve agents is due to the cleavage of the P-X bond, which irreversibly suppresses the production of the enzyme acetylcholinesterase, which is essential for the functions of the nervous system. This enzyme hydrolyses the neurotransmitter acetylcholine, leading to its accumulation, resulting in paralysis. The nerve agents act on the muscarinic and nicotinic receptors within the central nervous system leading to harmful effects (Sidell et al., 1992). The general effects of nerve agents are constriction of the pupil, urination, defecation, nausea, heavy breathing, muscle cramps, convulsions, cardiac arrhythmias, and paralysis. Nerve agents are lethal in much smaller quantities (Bajgar, 2004; Bajgar, 2005; Mars et al., 2006).

Blistering agents

Blistering agents are also called vesicants. These are toxic compounds that cause skin injuries in blisters resembling burns. The lungs and upper respiratory tract are severely affected (Davies et al., 2001). Mustards and arsenicals are two forms of blistering agents. Mustards are pale yellow to dark brown oily liquids (Shea, 2003). Mustards are insidious substances that can penetrate through leather and fabric, causing painful burns on the skin. Sulfur mustards, nitrogen mustards, and lewisite's fall under this category. The toxicity of mustards is due to covalent bonding and the formation of cyclic ethylene sulphonium ions. They bond to glutathione, causing enzyme inactivation and lipid peroxidation (Malhotra et al., 1999; Geohegan et al., 2002). They also cause injury to the eyes. Mustards are colorless and odorless liquids in pure form. Mustards are lipophilic and have less solubility, volatility, and stability. Diphenyl chloroprene is a mask breaker that can intrude the protective mask and damage the respiratory system (WMD, 2011) 2-chlorovinyl dichloramine is known as lewisite. It is volatile and has an irritating odor. The absorption rate of lewisite is rapid and causes immediate pain and irritation. It inhibits anaerobic glycolysis (Somani, 1992).

Blood agents

Blood agents are metabolic poisons that affect the use of oxygen in cells by interrupting the electron transport chain (Shea, 2003). Cyanide containing chemicals such as hydrogen cyanide, cyanogen chloride fall under this category. Cyanides have a high affinity towards iron in +3 oxidation state, affecting oxygen supply to tissues leading to respiratory failure (Raza et al., 1994). The effects of cyanide attacks are giddiness, headache, nausea, vomiting, respiratory failure, cardiac irregularities, and convulsions. Cyanogen chloride leads to lachrymatory and choking effects.

Choking agents

Choking agents are those chemicals that affect the nose, throat, and lungs. Generally, they cause difficulty in breathing and permanent damage to the lungs. The attacks are termed 'dry land drowning' as the lack of oxygen leads to death. Chlorine, phosgene, ammonia, diphosgenes, nitric oxide, and perfluoroisobutylene (PIFB) fall under this category. These chemicals are normally denser than air, have marked odours, and color the surroundings. Chlorine is a greenish-yellow gas with a pungent smell. It is an oxidizing agent and forms hydrochloric acid, hypochlorous acid, and oxygen free radicals on reaction with water. In recent times they have been encountered during industrial accidents. Phosgene is a colorless gas with the smell of hay. The carbonyl group attached to chloride atoms reacts with water to form carbon dioxide and hydrochloric acid causing damage to the cells and membrane in the lungs (Cucinell, 1974). Exposure to low concentration results in chest discomfort, shortness of breath, irritation of the nose, throat, and eyes. Higher concentration leads to swelling of lungs, respiratory failure, and death (Diller, 1985).

Psychomimetic agents

Psychomimetic agents are psychic incapacitants that cause changes in thought, mood, and perception without affecting the nervous system. They cause psychotic disorders such as loss of feeling, hallucinations, and paralysis. Dizziness, vomiting, blurred vision, irrational fear, inappropriate laughing are normal symptoms. Lysergic acid diethylamide (LSD), kolokol-1, marijuana derivatives, belladonna plants, 3-quinuclidinyl benzilate (BZ) fall under this category. BZ is the only incapacitating agent, accepted formally and NATO coded. Psychomimetic agents are predominately glycolates (Ganesan et al., 2010; Geohegan et al., 2002).

Riot control agents

They are also called lachrymatory agents or nonlethal agents as they are used in crowd control without casualties. Tear gases such as 2-chloroacetophenone (CN), 2-chlorobenzilidinemalononitrile (CS), dibenzo (b,f)-1,4-oxazepine (CR), and pepper spray fall under this category. They are solids and dispersed as aerosols. They cause strong irritation to mucous membrane, eyes and may lead to temporary blindness (WMD, 2011; Beswick, 1983).

Toxins

Toxins are poisonous chemical compounds produced by living organisms such as bacteria, fungi, and land or sea animals. Protein toxins and non-protein toxins are the two types. They are classified as dermatotoxins, hepatotoxins, cardiotoxins, and neurotoxins based on the mechanism. Botulinum toxin, called agent X, is a potent neurotoxin. Staphylococcus enterotoxin B is an incapacitating toxin. Ricin extracted from castor beans is a very potent phytotoxin that can cause instant death. Toxins as chemical agents are restricted to individual assassinations or localized terrorist attacks (Madsen, 2001).

Apart from the above-mentioned chemical agents, defoliants ‘Agent orange and Super orange”- a mix of two herbicide chemicals, 2,4- dichlorophenoxy acetic acid and 2,4,5- trichlorophenoxy acetic acid were extensively used in the Vietnam war. They release dioxins which is detrimental to human beings.

Chemical Disasters

A chemical disaster is a huge industrial accident involving chemical agents causing massive environmental damages. The victims need external help to recover and cope-up with the effects of such disasters. Chemical disasters are emergencies caused by identifiable human actions, either deliberate or otherwise. These disasters are complex and sudden. The predictability is nil, and the forecasting and warning are impossible (UNDP, 1992). Chemical disasters are highly challenging as they are multifaceted. They are caused due to explosives, gases, flammable solids and liquids, oxidizing substances, organic peroxides, toxic substances, radioactive materials, and corrosive substances. These lead to physical, health, and environmental hazards (OPCW, Central analytical database, 2017). The progress in modern technology and the rapid growth of chemical industries have led to chemical accidents. London smog, Minamata disaster are a few examples. Toxic chemicals such as arsenic, asbestos, ammonia, lead, formaldehyde, toluene, hexane, chlorine, etc., having industrial uses led to harmful disasters. Accidents/Explosions near vehicles containing hazardous chemicals also lead to disasters. Major accidents are caused due to freak incidents of flammable and toxic substances release, due to material handling at manufacturing installations. Bulk storage, handling, and transportation of industrial chemicals are inevitable, posing a threat to industrial employees, neighboring communities, and the environment. Chemical disasters result from improper design, poor maintenance, and non-compliance to safety standards.

Appropriate site selection after environmental and risk impact assessment, containing low levels of lethal storage, periodical safety auditing, proper maintenance are some of the measures to ward off chemical accidents (Malik, 2005).

Chemical Disaster Management

Chemical disaster management is defined as an activity to integrate several interrelated components to work in an effectively coordinated manner to ensure efficient management of available resources to safeguard the life of people and their rehabilitation. Chemical disasters create mass destruction and impede the progress of the people. The approach towards chemical disaster management has undergone a radical change. There is a paradigm shift from tackling the incident to preventing it by adopting a holistic approach. Chemical disaster management as an activity involves reducing the risk associated with such incidents through timely measures, long-term and short-term policies, providing the required assistance to the victims, and ensuring sustained recovery (Carter, 1991). At present, the focus is on hazard vulnerability, risk assessment, disaster prevention, and towards sustainable development.

The chemical disaster management falls under the Sendai Framework for Disaster Risk Reduction 2015-2030. The Geneva protocol of 1925 prohibited the use of chemical weapons in warfare. In 1968, the conference on disarmament adopted the Chemical Weapons Convention (CWC), which came into force in 1995, aimed at the destruction of chemical weapon stockpiles and their associated production facilities; non-proliferation of chemical weapons and its assistance in protecting the world nations from chemical attacks. The CWC provides a legal framework and institutional support structure to effect prohibition. The Organisation for Prevention of Chemical Weapons (OPCW), established in 1997, played an important role in wiping out 97% of chemical weapon stockpiles (OPCW Declarations Handbook, 2017). Both these organisations invoked` a non-discriminatory multilateral disarmament approach and non-proliferative regime in ensuring transparent and credible management of disasters out of chemical terrorism and chemical accidents.

Chemical disaster management can be effectively executed by creating institutional measures at different regions, country, state, and local levels. Each country sets up different departments for setting and monitoring safety standards. Chemical disaster management includes hazard mapping, hazardous material identification, inspection of chemical plants and storage facilities, monitoring toxic waste disposal, monitoring pollution levels, creating awareness among workers in hazardous industries, establishing the procedure for warning, immediate action plan, fixing responsibilities of officials, providing effective training, plan for casualty evacuation and medical aid, constructing firefighting arrangements and creating command, control, and communication system. Chemical disaster emergency management is to be devised for onsite and off-site contingencies. Suppose the accident's impact is confined to a particular area and expected to cause damage or destruction of the plant, equipment, and injury or loss of life of the workers. In that case, it is said to be an onsite contingency. If the impact is widespread and beyond the premises of hazardous industrial unit, then it is said to be off-site contingency (Parasuram et al., 2000; Siromony et al., 2000; UNDP, 1992).

The management activity comprises two phases. They are the pre-disaster phase and post-disaster phase. Prevention, preparedness, capacity building, and planning come under the pre-disaster management phase. Detection, decontamination, response, medical response, rescue, relief, recovery, restoration, rehabilitation, remediation come under post-disaster phase (Bharadwaj et al., 2007).

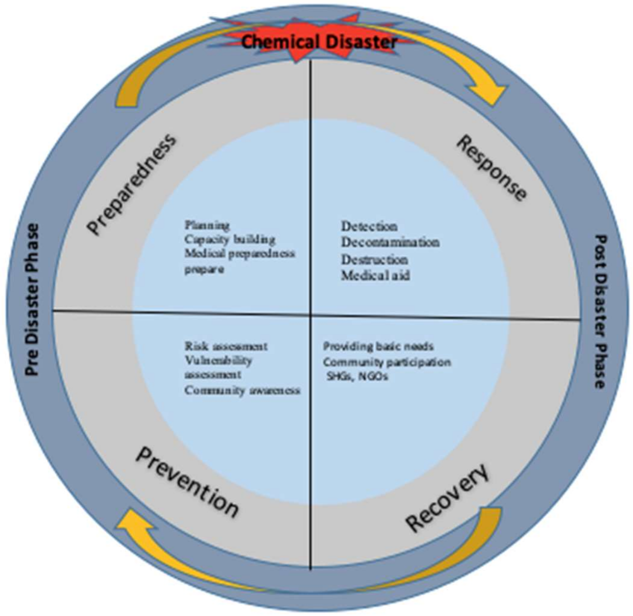

Figure 1. Chemical Disaster Management

Pre-disaster Management

In this phase, various agencies empower themselves to face the challenges of chemical disasters in a pre-emptive mode. Stakeholders such as first responders, security agencies, medical and health agencies, fire and rescue services, other government and inter-governmental bodies, NGOs, communities prepare themselves to counter the unforeseen situation with the help of expertise, knowledge, capacity, and resources.

Prevention

Chemical disasters/ terrorism cannot be prevented altogether. However, their incidence can be averted to a large extent by stringent acts of continuous monitoring and inspection of production, stockpiling, and transportation of hazardous chemical agents. Risk and vulnerability assessment, environmental monitoring and effective surveillance mechanism, intelligence gathering and proper dissemination of information, community awareness about threat perception can play a vital role in chemical disaster/ terrorism prevention. Risk assessment can be done based on short-term and long-term impacts on environmental parameters. Nanotechnology based miniaturized chemical-specific biosensors, thermo-gravimetric analyzers, and FTIR spectrometers can be used for environmental monitoring. GPS-enabled vehicles and identification of transport routes can be helpful to avert the landing of chemical agents and other hazardous chemicals into the hands of terrorists on transportation (Bharadwaj et al., 2007; OECD, 1996; Shrivastave et al., 1991). Counter-terrorism strategies, minimizing socio-economic factors leading to terrorism, zoning of vulnerable sites to chemical attacks, preparation of standard operational procedures (SOP) for a specific chemical attacks, prevention of illegal trafficking of hazardous chemical wastes would help avert the occurrence of chemical disasters/ terrorism.

Preparedness

Preparedness involves planning, the creation of infrastructure, and capacity building. It includes various time-dependent emergency tasks carried out by first responders, healthcare providers, voluntary organizations, laboratories, and other private agencies. Preparedness is an act of coordination among all the agencies involved to face unprecedented challenges. It is imperative to develop resilience among hazardous chemical industries, vital installations, and the community to create awareness, provide education and training to counter the unforeseen situation. Personal protection and medical preparedness are the two bare arms for effective preparedness. Two basic requirements of personal protection are the availability of breathable air and creating a barrier between chemical agents and people. Breathable air is provided by air cylinders which are a source of oxygen, and by detoxifying contaminated air. Respiratory protection may be achieved by self-contained breathing apparatus (SCBA) or chemicals filtering face masks. Full-face protective masks act as a barrier and safeguard the respiratory tract and eyes. The respiratory and body protection kit should be airtight and non-permeable to gases to prevent exposure to chemical agents. Permeable and impermeable suits are available for personal protection. Permeable suits are made of three layers consisting of oil, water, and fire retardant nylon fabric. Impermeable suits are nylon fabric coated with neoprene on the outer and butyl rubber on the inner side. Gloves and boots are made up of butyl rubber. The availability of suitable personal protective equipment (PPE) kit consisting of a face mask, suit, gloves, boots, and other protective gear is important to inculcate confidence among the first responders. Four levels of personal protection, such as A, B, C, and D, with different combinations of chemical protective clothing and respiratory protection, are used in dealing with hazardous chemicals (Ellison, 2000; Boopathi et al., 2008; Chan et al., 2002). Medical preparedness is a vital parameter in preparedness. Adequate number of basic life support systems in hospitals, sufficient number of beds, rapid detection kits, and decontamination facilities are to be prepared in advance for an effective medical response.

Capacity building

Capacity building refers to creating a skilled and trained workforce involving all the stakeholders and the community. A pool of human resources must be developed by imparting disaster-related education, knowledge management, and community awareness. Institutions to train first responders and infrastructures are to be developed. Capacity regarding material logistics, infrastructural facilities, and networking communication is inadequate at the level required to mitigate chemical attacks. Training facilities, professional bodies, industrial agencies, corporate institutions, health care providers, and communities need to synergize their activities to augment the capacity related to chemical terrorism and disaster management. Communication and networking between various stakeholders and sensitive organizations must be effective and quick to carry out immediate responses (Banks, 2015).

Post – Disaster Phase

The post-disaster phase is the important phase where the impact of the disaster borne by the community is to be mitigated. Chemical attacks are localized and affect living organisms within a short period. The impact of persistent chemical agents is immediate with long-term effects, and non-persistent chemical agents are less as they can disperse rapidly due to their high evaporation rate. Hence the initial period of impact is very crucial. It is very important to know about the attack and the cause to carry out an effective response. The different stages in this phase of response, relief, rehabilitation, and recovery are made by early warning signs and detection, decontamination, evacuation, and medical response (Bharadwaj et al., 2007).

Early warning signs

Hazardous chemicals possess warning properties that can be perceived by human senses, such as smell, sight, irritation to skin, eyes, and lungs. Few chemicals which are colourless and odourless are imperceptible. Death of wild or domestic animals and birds on a small or large scale, death of fishes in the aquatic environment, lack of insect life or abnormal insect activity in ground or water surface, the occurrence of blisters, rashes, pinpointed pupils, respiratory problems, nausea, vomiting, convulsions to human beings, discoloured leaves or loss of foliage in trees, shrubs, bushes, food crops, presence of unusual oily droplets, low lying clouds, a fog-like condition in the atmosphere, etc., are the early warning signs or indications of a possible chemical attack. The knowledge about the hazardous chemical used will facilitate appropriate antidote administration and effective treatment for a speedy recovery (Gilbert Gedon, 2002).

Detection

Detection of chemical attacks could be useful in many aspects. It will provide the time to react, identify the chemical agent to provide better response and effective treatment. Early detection about the type and nature of the chemical agents used may provide vital information for proper management. Even though various effective and inexpensive detection technologies, from basic calorimetric technology to advanced ones, are widely available, no detectors can rapidly alert people to a wide range of chemical hazards. Many handheld detection devices such as Three Colour Detector (TCD) paper, Residual Vapour Detection (RVD) kit, Water Poison Detection (WPD) kit are available. Chemical detectors identify specific agents as they do not possess universal properties. TCD paper turns green to V-nerve agents, yellow to G-nerve agents, and red to mustard agents. Chemical agents in the air are identified by using an RVD kit. It sucks air and detects the chemical by a colour change in the silica present in the tubes.

Phosgene, hydrogen cyanide, and cyanogen chloride in the air are detected with high specificity. The instruments utilize ion mobility spectrometry (IMS) as in chemical agent monitor (CAM), M8A1, M-90; automatic chemical agent detector/alarm (ACADA); surface acoustic wave sensor (SAWS) as in Quartz Crystal Microbalances (QCM), Joint Chemical Agent Detector (JCAD); flame photometry as in AP2C of France, CHASE of Israel; gas chromatography (GC), and mass spectrometry (MS) as basic principles to identify chemical attacks (Baumbach et al., 1996; Collins et al., 2002). The complex technique of Gas chromatograph coupled with mass spectrum (GCMS) involved in instruments such as HAPSITE, EM series, MM1 &2 is the only technique used to detect psychomimetic agents (Makas et al., 2004). Advanced technologies such as molecularly imprinted polymer (MIP) technology, surface plasmon resonance (SPR) technology are in the developmental stage to develop effective sensors and biosensors. Passive infrared detector technology used in remote sensing chemical agent alarm (RSCAAL) can detect chemical agents in the vapour phase at a distance of 5 Km (Murray et al., 2005; Sun et al., 2005).

Response

Promptness, active involvement, and a high level of coordination among various responders and service providers account for effective response. The response plan is to coordinate with different agencies by establishing command posts, control rooms, relief centers, medical units, etc. The response to a chemical disaster consists of three phases. The first is the lifesaving phase, in which the victims are treated and evacuated to a safe zone. This includes evacuation or keeping the people indoors, sheltering the evacuees, and treating people. The victims are to be kept away from obvious plumes or dust clouds and taken away from the location. People should be asked to remain indoors and ventilation, air conditioners, and forced-air heating units and close fireplace dampers to be turned off. Covering the mouth, nose with a tissue, filter, or damp cloth could reduce exposure. Contaminated clothing to be removed and decontamination efforts to be carried out. To guide emergency evacuation and treatment during the acute rescue phase, zones of hazards such as high-hazard zone, hot zone, safe- zone to be designated.

The second phase involves evaluating the extent of contamination, taking measures to control it, and minimizing human exposure. The prompt ability to predict the exposure and exercise decontamination procedures are included. The last phase involves the recovery and cleanup efforts of decontamination and remediation of contaminated property. The responders to be donned PPE or turnout gear. For respiratory protection, the air-purifying respirator or N95 barrier mask is used. Eating or drinking in the area of dust and debris to be avoided. Summary of damage analysis, vulnerability assessment, details of affected zone demarcation, resources available to handle on-site emergencies, and off-site relief are required to respond effectively. Situational assessment and rapid mobilization of trained responders account for a swift response. Information about the site, including locations of hazardous substances, technical information about such chemicals and their dangers, emergency evacuation routes, meteorological information, temporary food and shelter locations, fire-fighting materials, damage control, and repair items are familiar to first responders. They should be in a position to carry out stoppage of affected plant/system, replacement of operation staff, evacuation of employees/visitors or civilians to safety areas, isolating the leaky areas, and first aid (Bharadwaj et al., 2007; Bhawane et al., 2011).

Decontamination

Decontamination is defined as converting or removing the toxic chemicals from the environment, equipment or people by destruction or detoxification into harmless products. This is done either by chemical neutralization or by physical removal. Physical decontamination is done using absorbents such as Fuller's earth, kaolin, flour, talc, sawdust, activated carbon, soil, etc. Dry formulations such as PDK-1, PDK-2, M-291 kits are readily available for decontamination of equipment and skin. Chemical decontamination is the conversion of hazardous chemical agents into innocuous products. This process is either an oxidation reaction or a nucleophilic reaction. Bleaching powders such as high test hypochlorite, super tropical bleach, dutch powder, activated solution of hypochlorite were used as early decontaminants. Sodium or potassium hydroxide dissolved in ethanol or methanol is also used in decontamination. Chloramines are effective decontaminants for V-agents, and sodium carbonate is effective against G-agents. A standard decontaminant DS2, containing 70% diethylenetriamine, 28% ethylene glycol monomethylether, and 2% sodium hydroxide, is effective against all toxic chemical agents. Reactive skin decontaminant lotion (RSDL) containing alkali metal salt of phenol, acetone, oxime, acetophenone oxime, 2,3-butanedione monoxime, and tetraglyme solvent is effective against V and G type nerve agents. The American decontamination kits (M258A1 and M280) contain 72% ethanol, 10% phenol, 5% sodium hydroxide, ammonia, and water, the German decontamination system C8 containing 76% water, 15% tetrachloroethylene, 8% calcium hypochlorite, and anionic surfactant are effective decontaminants used extensively. An advanced multi-purpose chemical, biological decontaminant (MCBD) based on microemulsion system containing 60% water, 28% n-cetyl trimethyl ammonium chloride, 7% tetrachloroethylene, and traces of (n-Bu)4 NOH is also developed. For all hazardous chemical agents, the immediate decontamination action can be done by simple means such as removing the clothing, washing the skin gently with soap water, not abrade skin on washing or rinsing, and flush eyes with plenty of water or normal saline (Seto, 2009; Yang et al., 1992; Kim et al., 2011; Dobes et al. 2018).

Destruction of Chemical agents

The herculean task is to destroy hazardous chemicals and chemical agents without any adverse effects on the environment. Initially, disposal methods of chemical weapons include land burial, sea dumping, firing, or exploding the munitions by detonation and open-pit burning. But these methods pose threats to environmental degradation. Buried munitions and chemical agents contaminate the surrounding soil and penetrate the water sources. Sea dumping adversely affects marine resources. CWC permits two technologies to destroy chemical weapons, such as incineration and chemical degradation. Incineration is when the chemical agent is removed from the munitions by automated equipment. Chemical degradation is the process of neutralizing the chemical agents on reaction with other chemicals such as alkalis and oxidants to negate the toxicity (Malik 2005; Kim et al., 2011).

Treatment

Treatment for each type of attack is agent-dependent and varies with the quantum of exposure. Atropine and pralidoxime chloride serves as an antidote for nerve agents. Diazepam (valium) addresses the seizures and convulsions due to nerve agent exposures. Effective treatment should start before the attack or immediately after the exposure. Amyl nitrite or sodium nitrite combined with sodium thiosulfate can reverse the effects of blood agents such as cyanides. Pre-exposure use of pyridostigmine bromide protects nerve agent soman, but it should be used during the imminent threat of chemical attack. For respiratory agents, the best treatment is exposure to fresh air and proper ventilation (Ganesan et al., 2010; Shea, 2003; Geohegan et al., 2002).

Recovery, Relief and Rehabilitation

A multi-pronged, inter-sectorial approach is necessary for recovery, rehabilitation, and recovery. Providing the basic amenities such as food, clothing, and shelter remains the primary task. Various departments such as Police, Fire and Rescue, Revenue, Food and Agriculture, Water Supply, Electricity, Public Health, Transportation and their services are necessary for relief, rehabilitation, and recovery. Community participation, village defense committees, involvement of local communities, self-help groups, and women organizations are very effective in providing relief and rehabilitation (Bharadwaj et al., 2007; Bhawane et al., 2011).

Research and Development

There is a need for research and development in the existing technologies in upgrading personal protective equipment separately for the aged, infants, and children. The development of biomarkers and bio-indicators for chemical identification and therapeutic intervention is the need of the hour. Development of advanced detection mechanisms, monitoring technologies, and mobile decontamination facilities is required to carry out post-disaster management (NDMA Guidelines, 2009)

Challenges

Even though 97% of the chemical weapon stockpiles were destroyed and 90% of the world population lives free of chemical weapons, challenges remain due to the increasing universality of chemical agents and their versatile usage in a clandestine manner.

Even recently, the usage of chemical weapons in Syria and targeted assassinations using chemical agents in the form of chemical terrorism against world leaders have been reported. The re-emergence of chemical weapons and the failure of some member states to safeguard national implementation and ensure compliance with destruction deadlines is a matter of concern.

Conclusion

The dimension of the threat due to chemical terrorism and chemical disasters is ever looming. Unless we prepare to face the eventualities of these disasters, its mitigation and recovery are very arduous. To confront this, the basic knowledge about chemical terrorism, chemical disasters, and its management through various stages is essential and provided to the first responders. Through this review, the author provides such information, which would be helpful to various stakeholders in countering the menace to safeguard humanity.

References

Aas, P. (2003). The threat of mid-spectrum chemical warfare agents. *Prehospital and Disaster Medicine,* 18(4):306-12. doi: 10.1017/s1049023x00001254.

Bajgar, J. (2004). Organophosphates/nerve agent poisoning: Mechanism of action, diagnosis, prophylaxis, and treatment. *Advances in Clinical Chemistry*, 38:151-216. https://doi.org/10.1016/s0065-2423 (04)38006-6.

Bajgar, J. (2005). Complex view on poisoning with nerve agents and organophosphates. *Acta Medica*, 48:3-21. https://doi.org/10.14712/18059694.2018.23

Banks, W. C. (2015). Law and terrorism in the US and beyond. *International encyclopedia of social and behavioural sciences*, 2 nd edition, Elsevier, oxford, UK. 528-534.

Baumbach, J. I., & Eiceman, G. A. (1999). Ion mobility spectrometry: Arriving on site and moving beyond a low profile. *Applied Spectroscopy,* 53:338-55. doi: 10.1366/0003702991947847

Beswick, F. W. (1983). Chemical agents used in riot control and warfare. *Human Toxicology*, 2:247-56. doi: 10.1177/096032718300200213

Bharadwaj, J. K., Chawla, R., & Sharma, R. K. (2007). Chemical disaster management: Current status and perspectives. *Journal of Scientific and Industrial Research,* 66: 110-119.

Bhawana, P., & Fulekar, M. H. (2011). Environmental management- strategies for chemical disaster. *Research Journal of Chemical Sciences*, (1): 111-114.

Boopathi, M., Singh, B., & Vijayaraghavan, R. (2008). A review on NBC body protective clothing. *The Open Textile Journal,* 1:1

Carter, W. N. (1991). Disaster Management: A Disaster Manager's Handbook, ADB, Manila.

Chan, J. T., Yeung, R. S., & S. Y. Tang. (2002). Hospital preparedness for chemical and biological incidents in Hong Kong. *Hong Kong Medical Journal,* 8:440-446.

Collins, D. C., & Lee, M. L. (2002). Developments in ion mobility spectrometry-mass spectrometry. *Analytical and Bioanalytical Chemistry,* 372:66-73.

Convention on the Prohibition of the development, production, stockpiling and use of Chemical Weapons and Destruction, Technical Secretariat of Organization for Prohibition of Chemical Weapons, The Hague. (1997). http://www.opcw.org.

Cucinell, S. A. (1974). Review of the toxicity of long term phosgene exposure. *Archives of Environmental Health,* 28:272-5.

Davies, K. G., & Aspera, K. (2001). Exposure to liquid sulfur mustard. *Annals of Emergency Medicine,* 37:653-6. doi: 10.1067/mem.2001.114322.

Diller, W. F. (1985). Therapeutic strategy in phosgene poisoning. *Toxicology and Industrial Health*, 1:117-28. doi: 10.1177/074823378500100212.

Dobes, P., Novotny, P., Baudisova, B., Moracova, I., Schreiberova, & Danihelka, P. (2018). Basic concept towards protection against chemical terrorism, *Chemical Engineering Transactions,* 67:859-864.

Ellison, D. H. (2000). Handbook of Chemical and Biological warfare agents, Boca Raton, FL: CRC Press. p.472.

Ganesan, K., Raza, S. K., & R. Vijayaraghavan, (2010). Chemical warfare agents. *Journal of Pharmacy and Bio-allied Sciences,* 2(3):166-178. doi: 10.4103/0975-7406.68498.

Geohegan, J., & Tong, J. L. (2006). Chemical Warfare Agents. *Continuing Education in Anesthesia, Critical care and Pain,* 6:230-234.

Gilbert Gedeon, P. E. (2002). Building terrorism mitigation- Blast and CBR measures, FEMA 426, Reference manual to mitigate potential terrorist attacks against buildings, Chapter 5. www.cedengineering.com.

Hoenig, S. L. (2007). Compendium of chemical warfare agents, New York, U.S.A, Springer.

Kim, K., Tsay, O.G., Atwood, D.A, & Churchill, D.G. (2011). Destruction and detection of chemical warfare agents. *Chemical Reviews,* 9:5345-5403. doi: 10.1021/cr100193y.

Krstic, M. M. (2017). Tendency of using chemical, biological, radiological and nuclear weapons for terrorist purposes. *Vojnotechnicki glasnik*, Military technical courier. 65(2): 481-489.

Lopez-Munoz, F., Alamo, C., Guerra, J. A., & Garcia-Garcia, P. (2008). The development of neurotoxic agent as chemical weapons during the National Socialist period in Germany. *Revue Neurologique*, 47:99-106.

Madsen, J. M. (2001). Toxin as weapons of mass destruction. A comparison and contrast with biological warfare and chemical warfare agents. *Clinical Laboratory Medicine,* 21:593-605.

Makas, A. L., & Troshkov, M. L. (2004). Field gas chromatography-mass spectrometry for fast analysis. *J Chromatogr B Anal Tech Biomed Life Sci,* 800:55-61.

Malhotra, R. C., Ganesan, K., Sugendran, K., & Swamy, R. V. (1999). Chemistry and toxicology of bis(2-chloroethyl)sulphide (mustard gas)- a review. *Defence Science Journal,* 49:97.

Malik, P. (2005). The challenge of Chemical disaster and management, *International Journal of Research in Engineering and Applied Sciences,* 5(1).

Mars, T. C., Rice, P., &Vale, J. A. (2006).The role of oximes in the treatment of nerve agent poisoning in civilian casualties. *Toxicological Reviews*, 25:297-323. doi: 10.2165/00139709-200625040-00009.

Murray, G. M., & Lawrence, D. S. (2005). In: Chemical weapon Convention Chemical Analysis, Mesikaaskso M, editor. Chichester: John wiley and sons Ltd. pp. 65-88.

National Disaster Management Guidelines: Management of Chemical (Terrorism) Disaster. NDMA, Government of India. (2009). http://www.ndma.gov.in.

Nepovimova, E., & Kuca, K. (2018). Chemical warfare agent NOVICHOK- mini-review of available data. Food and Chemical Toxicology, 121 (2018)343-350. doi:10.1016/j.fct.2018.09.015

OECD, Guiding principles for chemical accident prevention, preparedness and response, OECD Publication service, France, (1996).

OPCW- Declarations Handbook for the convention on the prohibition of the development, production, stockpiling and use of chemical weapons, version 2, 2017.

OPCW- The most traded scheduled chemicals brochure, 2017.

OPCW - Protocol for naming compounds in OPCW central analytical database, version 6, 2016.

Patocka, J., & Fusek, J. (2004). Chemical agents and chemical terrorism. *Central European Journal of Public Health,* 12:S75-77.

Parasuram, S & Unnikrishnan, P. V. (2000). India Disaster Reports, Oxford University Press, New Delhi.

Raza, S. K., & Jaiswal, D. K. (1994). Mechanism of cyanide toxicity and efficacy of its antidotes. *Defence Science Journal,* 44:331.

Sage, W., & Wiener, M. D. (2004). Nerve agents: a comprehensive review. *Journal of Intensive Care Medicine,* 19:22-36.

Seto, Y. (2009). Decontamination of chemical and biological warfare agents, *Yakugaku Zasshi,* 129: 53-69. doi: 10.1248/yakushi.129.53.

Shea, D. A. (2003). Chemical Weapons: A summary report of characteristics and effects, Congressional Research Service, www.crs.gov.

Shrivastave, P., Millar, D., & Miglani, A. (1991). The evolution of crises: Crisis precursors, *International Journal of Mass Emergency Disasters,* 9: 321-338.

Sidell, F. R., & Borak, J. (1992). Chemical Warfare Agents II. Nerve Agents. *Annals of Emergency Medicine,* 21:865-71.

Siromony, P & Vetha, P. M. (2000). Source Book on Disaster Management, LBSNAA, Mussoorie, India.

Small, L. (2002). Toxic industrial chemicals: A future weapons of mass destruction threat. US Government Reports Announcements and Index.

Somani, S. M.(1992). Chemical Warfare Agents, U.S.A, Academic Press Inc.p.67.

Stuart, J. A., Ursano, R. J., Fullerton, C.S., Norwood, A.E., & Murray, K. (2003). Belief in exposure to terrorist agents: Reported exposure to nerve or mustard gas by Gulf war veterans. *The Journal of Nervous and Mental Disease,* 191:431-6. doi: 10.1097/01.

Sun, Y., & Ong, K. Y. (2005). Detection technologies of chemical warfare agents and toxic vapors. Boca Raton FL: CRC press.

UNDP, (1992). An overview of Disaster Management, 2nd edition, Part I.

Weapons of Mass Destruction- Chemical Weapons, Global Security.Org. (2011).

Yang, Y. C., Baker,J. A., & Ward, J. R. (1992). Decontamination of chemical warfare agents. *Chemical Reviews, 92:1729*-43.