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NAVIGATING THE REALM OF CHEMICAL HAZARDS

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ABSTRACT

Chemical hazards pose significant risks to human health, the environment, and various sectors of society. Understanding these hazards, their sources, and their impacts is crucial for effective risk management and development of appropriate safety measures. This review provides a comprehensive overview of chemical hazards, encompassing various aspects such as the types of chemicals involved, their sources, exposure pathways, and adverse effects on human health and the environment. The assessment also covers the handling, storage, and disposal of hazardous chemicals, stressing the significance of correct management to avert mishaps and lessen possible damage.

It examines different risk assessment techniques and regulatory frameworks used to manage and reduce chemical hazards in addition to the dangers themselves. In order to choose the best control methods, it addresses the significance of hazard identification, exposure assessment, and risk characterization. It also looks at how national and international bodies, as well as industry standards, set safety rules and regulations. This analysis highlights the complexity of chemical dangers, their effects, and contributes to collective awareness for efficient risk management, preventative measures, and environmental preservation.

**Keywords: Chemical hazards, Global regulatory agencies, Industrial waste, Maintenance,
Chemical emergencies, Goods Laboratory Practices etc.**

1. INTRODUCTION

The pharmaceutical sector is a critical aspect of the worldwide healthcare system as it engages in drug discovery, creation, production, and promotion. The industry relies heavily on the clinical design, examination, and advancement of medications, which significantly prevent or treat illnesses and conditions. Additionally, producing active pharmaceutical ingredients and drug formulations involves using various substances, including numerous corrosive and irritating agents like acids, bases, oxidising agents, and solvents. They are often found at exceedingly high levels. Being large, they are dangerous to the health of personnel [1].

During the 1960s, the chemical industry was flourishing, but at the same time, it became apparent that some chemicals were not safe or effective. There is a rising concern that these chemicals are spreading widely and could cause environmental issues if they remain in the environment. The media widely publicized chlorofluorocarbons (CFCs) as they are discovered to be responsible for the depletion of the ozone layer, which protects humans from harmful UV radiation and overexposure that may lead to skin cancer. However, many other cases of environmental damage due to the unchecked use of chemicals followed this discovery.

In Japan, mercury and cadmium contamination led to deadly diseases like Minamata and itai-itai, causing increased formulation of Standard Operating Procedures and protocols due to contaminated fish and rice [2, 3]. Polychlorinated biphenyls (PCBs), commonly used in paints and electrical transformers, are accumulating in human organs and the environment, causing toxic effects [4].

In 1976, in the Italian town of Seveso, highly toxic dioxins were released following an explosion in a local chemical factory, causing severe health effects on the local people and animals [5]. In 1978, the US city of Love Canal saw a significantly increased rate of congenital disabilities in children. This was found to be caused by toxic releases from chemicals which had been deposited in the local waste dump by a chemical company [6]. In the 1960s, the chemical sector experienced growth, but it also became evident that certain chemicals were unsafe or inefficient. The media extensively covered the discovery that chlorofluorocarbons (CFCs) were responsible for the depletion of the ozone layer. Additionally, Rachel Carson's book, *Silent Spring*, published in 1962, shed light on pesticides' damaging impact on birds, particularly DDT [7]. The work resulted in the

ban of DDT in the United States in 1972. The book is recognised for playing a crucial role in starting the environmental movement, focusing more on better-managing chemicals and pesticides. F. Sherwood Rowland and Mario Molina wrote an article in the scientific journal *Nature* in 1974, providing evidence of the danger CFCs pose to the ozone layer in the stratosphere. Their work led to them being awarded the Nobel Prize for Chemistry in 1995, along with Paul Crutzen. A hazard is a circumstance that presents a potential danger to the well-being of individuals, their physical surroundings, or their property. On the other hand, a professional hazard can be defined as any situation created by organisations that may harm or damage employees, property, or goods. A chemical risk is an inanimate stuff that poses a risk to health. Chemicals are commonly found in households and various other settings. Being exposed to such substances can result in immediate or long-term health problems. There are numerous harmful chemical compounds such as neurotoxins, carcinogens agents that affect skin, immune system, and reproductive system that trigger asthma, cause pneumoconiosis, and sensitisers. Exposure to chemical risks is a type of occupational hazard in the workplace. By utilising personal protective equipment (PPE), individuals can

significantly reduce the risk of harm caused by coming into contact with hazardous substances. This study aims to investigate the tragedy's origins and cause of mass casualties, focusing on locating, categorizing, and presenting reasons using available information to understand the massive impact of the explosion. To accomplish this, several graphic representation techniques have been applied, including the Fishbone diagram, event sequence diagram (ESD), and accident causation model. The accident causation model, in particular, is crucial to this work because it illustrates the logical connections between various causative elements and aids in the understanding and retention of the relevant lessons. The 24Model, an enhanced version of common accident models, identifies and refines accident causes, enhancing safety and sustainability in high-risk industries like coal mining, building, aviation, and shipping, and has been used for accident analysis and prevention. Another aim of the article is to supply a brief and extensive overview of chemical risks experienced by the pharmaceutical industry, like the types of chemical dangers, their careful management, legislation in India, and their safety measures [8].

Accident Causation Model

Wang J. research team studied accident causation models, but struggled to accurately specify causes at each level. They compiled the benefits and drawbacks of various models and proposed an enhanced version called the 24Model, aiming to improve accident prevention through analytical procedures. In this model, "4" refers to the classification of causes at human and organizational levels including unsafe acts, defects in habits, inadequacies in safety management systems, and shortcomings in safety culture, with "2" referring to human and organizational causes. According to the 24Model, internal organizational factors are the primary cause of all accidents and pertain to both the organization and the individual. The 24Model identifies internal organizational factors as the primary cause of accidents, focusing on modifiable and controllable factors for improvement. External causes, such as natural occurrences, flawed designs, inadequate government oversight, and regulations, exacerbate internal ones. These external causes typically exacerbate internal ones. This work provides a protocol for using the 24Model in accident investigation, illustrating a flow chart with downward arrows representing the main phase, which includes identifying events, analyzing internal and external causes, and visualizing findings. An

overview of the consensus process utilized in accident analysis is provided below [8- 9]:

- The process involves segmenting accidents, identifying key events, and locating the disaster organization, including design institutes, interested parties, and regulators, to understand their progression and impact.
- The study identifies harmful acts and unsafe situations, categorizes them based on violations, personnel, materials, facilities, and locations, and identifies individual weaknesses in safety awareness and psychological state.
- The study utilizes the OH&S management system framework to identify and analyze shortcomings in the creation and application of an organizational safety management system, focusing on flaws in safety culture carriers, member comprehension, and external organizational causal factors.

2. HAZARDS IN PHARMACEUTICAL INDUSTRY

2.1 Chemical Hazards: These can be defined as those where possibly hazardous energy is released through the breakdown of the molecular relationship, like a total outcome of a chemical reaction (usually a reactive

chemical danger) [1]. Chemical handling is integral to daily routine in many laboratories. However, the risks and hazards remain unchanged for employees. Numerous organic and inorganic substances are corrosive to the skin and eyes, which can be toxic [10]. Complete protection should be offered with chemical compounds that can be treated, and conditions for treating any clean exposures or spills should be present in the laboratory.

In a laboratory, thermal burns can result from chemical reactions that produce heat, that may be dangerous. This shows the importance of protecting skin's surface from the possibility of burn-off and exposure. Similarly, improper ventilation inside the laboratory might be hazardous. A distillation or chemical reaction may lead to a surge in the lab without complete and proper airflow [11]. Dependent on the dimensions of the wave and the materials impacted, this might be hugely dangerous for the united group and the laboratory.

Breathing particular chemical compounds is dangerous, with many solvents commonly being excessively toxic. These perils could be immediate or gradually manifest over time-which makes it crucial that the investigation staff are safeguarded from the fumes created by these hazardous chemical substances. Ingesting chemical substances is a massive

risk in many laboratories due to the contamination of fingers, drinks and food. This shows the importance of a safe storage space that protects all food and drink products from chemical publicity. Moreover, thorough hand-washing and sanitation terms should always be available for many people in the study group subjected to dangerous chemicals.

2.2 Physical Hazards: A physical hazard is the most widespread hazard. Physical hazards are circumstances, factors, or agents which will harm after making contact. These dangers are prevalent throughout various industries, especially in the pharmaceutical sector. The following are some examples of physical dangers.

- Explosiveness
- Gases under pressure
- Liquefied gases
- Dissolved gases
- Water-activated flammable gases
- Flammable gases
- Flammable liquids
- Flammable solids
- Self-reactive substances
- Pyrophoric liquids and solids
- Self-heating substances
- Dangerous when wet substances
- Oxidizing liquids and solids

- Oxidizing peroxides
- Corrosive substances or a mixture of materials

2.3 Biological Hazards: Using bacteria, viruses, blood, tissue, and bodily fluids in laboratory can lead to potential biological hazards. These products can all carry dangerous diseases or contaminants and could increase the lab group's risk [12]. In workplace, it is essential to safeguard employees from biological hazards such as animals, plants, and various environmental factors. Precautions must be implemented to prevent the risk of exposure to such hazards, and if this is not feasible, then measures must be taken to reduce the risk to an acceptable level [13]. Control measures, which involve various procedures, must be put in place to minimize the possibility of exposure to biological hazards. The consequences regarding the illnesses and contaminants can be immediate or take significant time, showing the value that most people in the laboratory group receive enough security, even when the risks are not understood [12, 14].

- Biological Risks Inside a Laboratory

The United Group sends the conditions carried by humans and organisms utilised in the study, just those who could become carriers. This means biological risks could

show to be a threat; this is undoubtedly huge, not just the laboratory specialists using the materials, but anyone arriving into contact with outside of work [15]. Occasionally, highly infectious biological risks (bio-hazards) could be among the most significant dangers of a modern-day study. Hence, every consideration must ensure that the team and the wider public are shielded against contagious materials [12, 16].

2.4 Electrical Hazards: Electrical fires are another common laboratory hazard which can occur when incorrect or unsafe cords and plugs are used. Any electrical appliances used in the laboratory should be fit for purpose and up-to-date and correspond to connected devices before they are implemented. Any electrical apparatus, from adaptors to cables, not safety-tested could compromise the safety of the lab and research team. Several primary electrical dangers encountered in the pharmaceutical industries include:

2.4.1 Sparking: Electrical arcs or flashes can cause sparking, flames, burns, and explosions due to defects or inadequate maintenance. Ensuring safety for all involved is crucial which can be done by:

- Evacuate the area: Immediately evacuate the area and ensure all personnel are safe. Sound the alarm

- and evacuate the building if necessary.
- Isolate the source of the sparking: To isolate the source of sparking, identify the equipment or machinery that caused it and turn off power if possible.
 - Call the emergency services: To address a situation, it is crucial to contact the appropriate emergency services, such as the fire department or paramedics and request their assistance.
 - Assess the situation: After evacuation and isolation of sparking source, assess the situation to determine the extent of damage and associated risks.
 - Implement corrective measures: Once the sparking's cause has been determined, take the necessary corrective action to stop a recurrence of the incident.

2.4.2 Existence of live wires: These pose a major risk of electrocution if they come into contact with skin. Within pharmaceutical industry, machinery or equipment that has been damaged or improperly grounded may contain live wires.

2.4.3 Barely electrical equipment: Negligently maintained electrical equipment can be extremely dangerous. Accidents such

as electrocution and fires can be caused by defective equipment.

3. CHEMICAL HAZARD TYPES IN LABORATORY

3.1 Irritants: Irritants may have a reversible inflammatory effect at the point of contact. The respiratory system, skin, and eyes may be impacted. Almost any chemical has ability to reduce or increase amount of interaction with structure. Acids, cleansers, ammonia, diesel exhaust, chlorine, cement, and welding fume are a few examples [11, 17].

3.2 Corrosives: Corrosive agents, such as hydrogen peroxide, sodium hydroxide, bromine, and sulfuric acid, can irreversibly damage living tissue and degrade non-biological surfaces like metals [12, 18].

3.3 Sensitizers: A significant percentage of patients who are exposed to sensitizers typically experience allergic responses. Hypersensitivity to sensitizers can deteriorate with repeated exposure and last for an entire life. Because of high level of exposure, this can happen at work. Low dosages of sensitizer can make the allergy worse outside of the laboratory. One such example is formaldehyde, which is produced when steam escapes from wall coverings, plywood, upholstery, permanent press clothing, and other building supplies.

3.4 Carcinogens: A carcinogen designation can be obtained under several conditions depending on the company. Formaldehyde, chromic acid, potassium dichromate, nickel chloride, chloroform, and dioxane are a few examples. Auramine O and any colors generated from benzidine, such as Congo red, acetone, ethanol, dichloromethane, chloroform, and dimethyl sulfoxide, are among the several dyes that are also carcinogenic [19].

3.5 Toxins or Poisons: Toxins, such as uranium nitrate, chromic acid, osmium oxide, and methanol, can be fatal if consumed or absorbed, potentially affecting organs or cellular processes [20].

3.6 Flammables and Combustibles [21, 22]:

The flash point of flammables and combustibles varies. The temperature at which vapours will ignite in the presence of an ignition source is known as flash point; however, this temperature may not always correspond to the point at which a substance may spontaneously ignite. Combustibles exhibit flash points at temperatures over a certain point. Different enterprises have distinct requirements for specific temperatures. National Fire Protection Association (NFPA) categorizes these liquids into three groups based on their specific

requirements:

- Flammable Liquid:
- Class I- A: Liquids with a flashpoint below 73° F (23° C) and boiling point below 100° F. Examples diethyl ether and petroleum.
- Class I- B: Liquids with a flashpoint below 73° F and a boiling point at or above 100 ° F. Examples include ethanol and acetone.
- Class I- C: Liquids with a flashpoint between 73 and 100° F and no boiling point. Example is p-xylene [21].
- Combustible Liquid:
- Class I: Liquids having flashpoint below 73.4 °F (23 °C) and boiling point at or below 95° F (35° C). Examples include butyl alcohol, diethyl glycol, styrene, and turpentine.
- Class II: Liquids with flashpoint between 101- and 140-° F (39-60° C). Examples include diesel fuel and certain cleaning solvents.
- Class III- A: Liquids with a flashpoint between 141- and 199-° F (61-93° C). Examples include mineral oil and oil-based paints.
- Class III- B: Liquids with a flashpoint at or above 200° F (93° C). Example is neatsfoot oil [21, 22].

4. ACTIONS TO MINIMIZE CHEMICAL HAZARDS

4.1 Continue to communicate closely: To pass an initial safety assessment, communicate with workplace safety personnel and adhere to their individual safety notes. Get to know security firm employees and ask questions for concerns, as they are allies in maintaining lab security [23].

4.2 Execute routine safety inspections: Usually, prior to evaluation, the Security Office provides a checklist. Recommendations from initial evaluation might exist and should be considered. There will be a follow-up assessment to make sure the instructions are applied correctly. It is advised that certain protective workplaces can need safety inspections, or individual general protection inspections; the former covers biological hazards, while the latter covers physical and chemical radiological concerns. It's initial after that; institutional inspections may occur on a regular basis [24].

4.3 Implement and improve Standard Operating Protocols (SOPs): SOPs are guidelines for expected tasks and risk cooperation, developed by safety enterprises. Safety officers inspect and modify SOPs to meet regulations. Regular review is necessary, including emergency procedures and prompt evacuation in case of personal injuries.

4.4 Safety training: Biological storage lab personnel require safety training, available online or through offline training. The protection office is required to maintain records, it is a good idea to save copies of your records and to make calendar and schedule reminders for important occasions.

4.5 Observing, Documenting, and Reporting: Occupational exposure limits should be monitored based on science recommendations, and security firms should monitor spills and odours. Injury records and safety instructions should be kept, and accidents should be reported to safety workplaces and regulatory agencies. Acknowledging accidents helps prevent future incidents.

4.6 Managing Chemical Exposure

- Elimination and Substitution: Chemical exposure causes 50,000 worker fatalities and 190,000 illnesses annually. Lack of knowledge about risks is the cause. To oversee workplace chemical visibility, replace or restrict harmful compounds and ensure proper knowledge.
- Engineering control (closed system): A closed engineering control system can shield workers from exposure to steam and gas, ensuring continuous decrease in risks and close observation. Toxic or

highly flammable solvents and other (particularly volatile) substances must be moved through sealed pipelines rather than being poured outside.

- Local ventilation systems, such as hoods, pipes, and duct drains, help remove contaminants from the environment. However, hazardous fumes and dust must be treated before removal, and proper maintenance, cleaning, and filters are essential for safety.
- General Ventilation: In laboratory environments, general dilution ventilation can be used to maintain outdoor pollutants below the substance's TLV (threshold limit value), ensuring clean air supply and proper escapement, along with other safety precautions, when avoiding chemical substances.
- Preventive Clothing in Laboratory: Chemical Protective Clothing (CPC) for Preventive Clothes in Laboratory: CPC selection must be made for specific exposure to chemicals, i.e., substances that include the work situation (time extent, space constraints), method of disclosure, duration of exposure, types of garment seams and closures, and environmental work problems (temperature and humidity).
- Personal Protective Equipment (PPE)/

Gear: PPE is an essential as a final line of defense, and hazards are evaluated and reduced through technical means or work organization procedures. All PPE should be adjusted to include potential hazards without increasing risks due to workplace and working conditions. The companies must provide and maintain good-condition PPE, with workers being consulted and trained on its compatibility and use with other PPE.

- Sewage and Refuse: Dispose of sewage, refuse, and other waste in a safe, timely, and sanitary manner, identifying containers and pipes for waste material.

Chemical Emergencies

Another programme is undoubtedly concerned with emergency procedures. Chemical emergencies include casualties, fires, explosions and spills/leaks. These can be incorporated into an organisation's disaster preparedness provisions. Nevertheless, certain chemically related procedures can be required, such as suitable bottom-up solutions, exposures, poison antidotes, spill kits, or distinctive extinguishers. The management and avoidance of substance-related behaviors include:

- Prepare information systems beforehand time, such as signs and backup plans.
- Specific procedures for chemicals at risk,

regarding health and health consequences that are ecological

- Training of the emergency response team.

5. MAINTENANCE OF OVEREXPOSURE TO CHEMICALS

With a few notable exceptions, medical care of acute overexposure to chemicals requires three steps and are not specific, despite the fact that thousands of chemicals are regularly employed in industry.

- The victim is taken out of the spotlight.
- The first step is for individual to leave the display site.
- Rescue personnel have a duty to safeguard disabled individuals in need of rescue, but their own safety from contaminated air must come first.
- First and foremost, respirators and emergency lines must be used.
- It is advisable to wear suits that are chemically impermeable.
- Resuscitation: Resuscitation is the process of preserving a person's life who seems to be died (collapsed or shocked).
- If the person is distraught, resuscitation should begin promptly.
- Continued care is required, as with any other medical emergency.
- Decontamination
 - If skin or clothing has been contaminated, remove it immediately, then shower, and

take care of nails and scalp. Acute overexposure can cause signs like seizures, bronchospasm, dehydration, and arrhythmia requiring medical help. Companies should prepare a directory of medical administration approaches for hazardous chemical substances.

Contaminant refers to unwanted materials like dust and particles during manufacturing, analysis, or transportation. Contaminants can be functional or nuisance, with five primary contaminants in the pharmaceutical industry: particles, metallic ions, chemicals, bacteria, and airborne molecular contaminants (AMCs) [25].

6. INDUSTRIAL WASTE-COMPONENTS AND HAZARDOUS SUBSTANCES

Industrial waste contains hazardous substances like heavy metals (mercury, cadmium, lead, etc.), flame retardants (pentabromophenol, polybrominated diphenyl ethers (PBDEs), tetrabromobisphenol- A (TBBPA)), etc. which in turn making e-waste dangerous. Improper handling can pose significant human and ecological health threats. Some electrical components/parts are common, and most hazardous substances are retained in electrical equipment (Table 1) [25].

Table 1: A listing of compounds and constituents those are potentially hazardous

Source: <https://www.researchgate.net/publication/281368370>

S. No.	Components	Located in	Elements that should be avoided
1.	Cathode ray tubes	Old TV, PC, Oscilloscopes	Pb in cone glass Ba in electron gun Cd in phosphors
2.	Printed circuit boards	Ubiquitous, From beepers to PCs	Pb, Sb in solder Cd, Be in contacts Hg in switches Brominated Flames Retardants in plastic
3.	Batteries	Portable devices	Cd in Ni- Cd batteries Pb in lead acid batteries Hg in Hg batteries
4.	Gas discharge lamps	Backlights of Liquid Crystal Displays	Hg in phosphors
5.	Plastics	Wire insulation, plastic housing, circuit boards	Polyvinylchloride Brominated Flames Retardants

Note: Mercury (Hg), beryllium (Be), lead (Pb), cadmium (Cd), antimony (Sb)

7. GOODS LABORATORY PRACTICES (GLP)

In response to regulatory concerns regarding the authenticity and integrity of non-clinical safety data given to the Food and Drug Administration (FDA) in New Drug Applications (NDA), GLP was implemented in the United States throughout the 1970s. During inspections, the FDA found multiple examples of poor study design and execution, inadequate documentation, and even fraud at testing facilities. Following the Carroll hearings, the FDA published Proposed Regulations on GLP in 1976, which were later revised and finalized in 1979 as 21 CFR 58. In order to guarantee that reports on studies submitted to the FDA correctly represented the experimental work, the GLP regulations were created. Similarly, the US Environmental Protection Agency (EPA) encountered similar problems and published its GLP regulations in

1983. According to the Organisation for Economic Co-operation and Development (OECD) standards, good laboratory practise (GLP) is a quality system that concentrates on the organisational process and the circumstances surrounding the planning, execution, monitoring, recording, archiving, and reporting of non-clinical health and environmental safety studies. According to GLP principles, organizations must give roles and responsibilities to staff members in order to guarantee each study is well-managed operationally and to concentrate on parts of study execution that are crucial for reconstructing the complete survey. GLP principles cover various study classifications, including toxicity, mutagenic potential, carcinogenic potential, pharmacokinetics, and local tolerance studies, applicable to manufacturer's, contract facilities, universities, and public sector laboratories,

reducing inaccuracies and enhancing study credibility [26].

8. INDUSTRIAL ACCIDENTS

Frequent industrial catastrophes transpire within India throughout the previous decade. The National Disaster Management Authority (NDMA) collected records showing that more than one hundred thirty significant chemical incidents had place, leaving two hundred fifty-nine people dead and five hundred sixty-three seriously injured [27]. Thirty years after the Bhopal disaster, repeated industrial disasters continue in a country known for its industrial development and striving to emulate China's manufacturing hegemony. These are business-related events that cover small, medium, and large business sizes in the public and private sectors, including international corporations. A number of efforts aimed at lowering industrial accidents arose after the Bhopal disaster. These included the creation of environmental laws, construction of disaster relief agencies, and instruction of innumerable people in environmental preservation. The most catastrophic industrial accident in Indian history directly led to the creation of the NDMA.

8.1 Bhopal Gas Tragedy

The Bhopal gas tragedy, was a gas leak event on 2-3 December 1984 at the Union Carbide India Limited (UCIL) pesticide plant in

Bhopal, Madhya Pradesh, India. It is listed as one of the world's worst catastrophes. Methylisocyanate essence (MIC) was exposed to 500,000 individuals. The highly hazardous material made its way across the small city. Over 3,800 people died instantly following the disastrous leak of over 40 tons of MIC gas from a pesticide plant in Bhopal, India. Countless more people were ill and died prematurely as a result [28].

Initially attempting to evade legal accountability, the corporation ultimately arrived at a settlement with the Indian government via intercession of the nation's Supreme Court, acknowledging moral liability. Despite paying \$470 million in compensation, this sum fell short given the substantial miscalculations regarding the long-term health impacts and vast number of those impacted. This calamitous event underscored the necessity for internationally binding environmental safety norms, proactive prevention tactics against comparable disasters, and robust industrial crisis readiness protocols. Subsequent to the Bhopal tragedy has seen exponential economic expansion accompanied by noteworthy enhancements within governmental policies and select sectors of industry. Nevertheless, extensive ecological deterioration and consequential negative

health outcomes persist throughout the nation [28].

8.2 Mumbai Port Chlorine Leak

More than 120 persons were impacted by a chlorine leak that happened at the Mumbai Port Trust (MPT), Sewri, Haji Bunder cargo facility on July 14, 2010, due to a dangerous occurrence. Students, laborers, port workers, and firefighters were among the victims; 70 of them were listed as critically injured. The leak was first discovered in the Sewri yard, which is next to the LBS College of Advance Life Time Studies and Research, at about 3:00 a.m. in the morning. There is empty ground on one side of the yard and a large sea on the other. The LBS hostels were fully cleared by 4:00 a.m., and ambulances and police vans took the injured to the hospital. Tragically, the clinical signs disappeared within a few hours. The Mumbai Police have filed a gas leak complaint against unidentified parties [27].

It was discovered that the chlorine cylinders responsible for leak had been left behind by an importer in 1997, almost ten years prior, and that the Mumbai Port Trust (MPT) had been unsuccessful in selling them. One specific chlorine cylinder among the 141 stored at the location, according to MPT authorities, was identified as origin of the leak. The crisis took more than six hours to contain, with rescue and relief crews from various organizations

working together to identify, seal, and clamp the leaking cylinders. Firefighters created water curtains in the area to reduce spread of gas cloud caused by leakage, which could have drifted towards sea due to air pressure. In response to presence of chlorine-containing cylinders, the National Disaster Response Force (NDRF) along with emergency personnel employed a solution comprising both caustic soda and water for the purpose of deactivation. Out of 105 cylinders that were discovered, only 100 were successfully cleaned, while remaining five had leaked residual chlorine. On average, it took six hours to clean one cylinder, and out of 100 cylinders, 16 were neutralized. It was noted that MPT did not have a chlorine neutralization tank, which is required for any facility that stores and uses chlorine to manage such situations. Additionally, the facility did not maintain safety systems or comply with safety regulations [27, 28].

8.3 Neurological Epidemic in Eluru, Andhra Pradesh [29]

On December 4, 2020, an unexpected occurrence featuring neurological manifestations such as seizures and loss of consciousness emerged within a southern Indian community. Within 3 days, approximately 400 individuals had been affected by this outbreak. In response, a

multidisciplinary team conducted investigative visits at the site. The team hypothesized that the cause might be attributed to an acute exposure involving pesticides, heavy metals, or mycotoxins based upon patient histories and physical examinations. Consequently, blood and urine specimens were gathered from symptomatic cases as well as asymptomatic controls for further analysis. Additionally, water and food samples were obtained to pinpoint the origin of the outbreak. 74% of blood samples from afflicted population in Eluru contained traces of Triazophos—an organophosphate pesticide—while 98% of their corresponding urine samples exhibited the presence of its metabolic byproducts. It was determined that likely culprit behind the outbreak was contamination of household water sources by Triazophos—a type of organophosphate pesticide. As a precautionary measure against recurring incidents, regular monitoring of pesticide residues in soil, water, and food supplies has been advised with increased diligence.

8.4 Vishakhapatnam Styrene Gas

In Visakhapatnam, Andhra Pradesh, India, a significant industrial accident transpired within Gopalapatnam's vicinity—an area situated near the city's periphery. This event stemmed from the neglect of LG Polymers

Chemical Plant located in R.R Venkatapuram Village. As a result of this lapse, a toxic vapor cloud expanded across a 3 Km radius. The NDRF reported 11 fatalities and more than one thousand individuals falling ill as a consequence of exposure to the hazardous gas. According to the company's paperwork submitted to the Union Ministry of Environment, Forest, and Climate Change, it had come to light that the LG Polymers facility lacked a proper environmental approval during its operations. The plant only had consent for establishment and consent for operation from the Andhra Pradesh Pollution Control Board, and has been operating without environmental clearance for over 20 years, despite expanding five times between 2006 and 2018.

During the COVID-19 lockdown in March 2020, the suspected source of the leak at the LG Polymers plant originated from neglected storage tanks. Investigation revealed that the failure of the tank's cooling system led to increased temperatures, resulting in the liquified chemicals evaporating into the atmosphere. Experts suggest additional potential releases of various chemical substances alongside styrene could also have contributed to the leakage. A First Information Report (FIR) was lodged against LG Polymers under several sections of the Indian Penal

Code, including charges related to creating a pollutive atmosphere (Section 278), negligent handling of dangerous materials (Sections 284 and 285), inflicting injury through acts endangering lives (Sections 337 and 338), and causing deaths due to reckless behaviour (Section 304) [30].

To mitigate risks associated with their plant, LG Chemicals announced plans to introduce retardants and inhibitors into the styrene storage tanks, aiming to prevent future occurrences of gas leaks.

8.5 Ammonium Gas Leak in Chennai

Over a dozen inhabitants of Periakuppam, Chennai have been admitted to hospitals following an incident involving a gas release during the night of December 26, 2023. Numerous nearby households vacated their residences owing to the impact of this discharge. At 3:30 a.m., the Tamil Nadu Pollution Control Board's (TNPCB) assessment revealed that ammonia concentration in the atmosphere was approximately 3 parts per million (ppm), which is equivalent to 2,090 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$). However, the permitted 24-hour average according to TNPCB standards is only $400 \mu\text{g}/\text{m}^3$. From 11:30 p.m. on December 26, 2023, until approximately 3:30 a.m., local communities near Ennore were potentially exposed to significantly

elevated concentrations of ammonia, likely surpassing the estimated levels reported by TNPCB. The Central Pollution Control Board (CPCB) classifies ammonia levels above $1,800 \mu\text{g}/\text{m}^3$ (24-hour average) as "severe". Such exposure could lead to immediate respiratory issues for healthy individuals and severe health consequences for those suffering from lung and cardiac conditions.

Response of Stakeholders:

- The Government of Tamil Nadu mandated the temporary suspension of facility until additional instructions are issued. To conduct a thorough investigation and provide recommendations to the administration, a specialized team consisting of representatives from the TNPCB, professionals from Indian Institutes of Technology Madras, staff from the CPCB's regional office, National Environmental Engineering Research Institute (NEERI), Central Leather Research Institute (CLRI), and Industrial Safety and Health Directorate (ISHD) has been established.
- The Southern Bench of the National Green Tribunal independently initiated proceedings regarding the event and instructed the TNPCB to submit a detailed report.
- Coromandel International Limited

announced that they will halt all unloading procedures and operational activities at port until corrective measures are implemented to address causes leading to leakage.

- Community leaders advocated for declaring Ennore as an area afflicted by industrial incidents. Their demands included legal actions against corporations found guilty of pollution and compensation for the victims who suffered from leak.

As part of relief efforts, hundreds of residents were relocated to secure locations through evacuation operations.

8.6 Chernobyl Disaster [31]

One of the most disastrous incidents to ever occur at a nuclear power plant is the Chernobyl tragedy. In the fifty-five-year history of nuclear power, it continues to be the only disaster of its sort. The reactor core completely melted as a result of this incident, and radioactive materials were significantly released. Chernobyl is the only nuclear disaster to cause occupational fatalities, despite radioactivity dispersion, and the most significant impact was psychological trauma, not physical harm. Chernobyl was a catastrophic nuclear disaster involving a poorly designed reactor, resulting in a core

meltdown and ten days of uncontrolled radionuclide emissions.

8.7 Love Canal Disaster, USA [32]

The Love Canal in Niagara County, New York, was a hub for hazardous chemicals disposal, leading to increased health risks like miscarriage, birth defects, and cancer, and contamination of air and water. The region experienced 12.5% of pregnancies resulting in three or more miscarriages, and 17.5% of children born with birth defects. Residents in the canal area experienced higher kidney and bladder cancer rates, and lack of government action led to public distrust. The public's outrage over the Love Canal led to states of emergency and the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, significantly impacting hazardous waste handling.

8.8 Minamata disease, Japan [2]

Minamata disease, a neurological syndrome caused by methylmercury-contaminated seafood, originated in Minamata Bay, Japan, between 1953 and 1956, with its cause identified in 1959. In 1952, methylmercury levels in Minamata Bay reached their peak due to increased discharge from a factory switching co-catalyst in 1951. By 1960, improved waste disposal methods reduced harmful substances discharge. In 1964-1965, a second outbreak occurred in Niigata

Prefecture, resulting in 2263 cases and 338 deaths, with fetal methylmercury poisoning first reported in womb exposure cases.

8.9 Fukushima Nuclear Disaster [33]

The Fukushima Nuclear Disaster, second only to Chernobyl, resulted in significant radioactive material discharge, leaving 150,000 people under evacuation, either due to government directives or personal volition. The devastating earthquake and tsunami caused a major nuclear power plant disaster, affecting four reactors and causing over nine months of contamination and marine ecosystem harm. The electric company and the national government are blamed for the disaster due to their miscalculations, including underestimating tsunami height, station blackout risks, and prolonged power outages.

8.10 Seveso Disaster, Italy [34]

Seveso, a community in Brianza, Italy, has a rich history of woodworking and furniture production, with a growing chemical industry. On July 10, 1976, a reactor at the (Industrie Chimiche Meda Società Azionaria) ICMESA plant, operated by Givaudan for Swiss multinational Hofmann-La Roche, released a toxic cloud, causing dioxin contamination in several locations. Residents were unaware of the explosion due to familiarity with gas leaks and lack of security measures, despite the factory's history of accidental pollution since

1945. Roche technicians failed to address a crisis, leading to increased chloracne cases in children near the factory, underscoring the need for proactive safety protocols in chemical factories.

8.11 Three Mile Island Incident [35]

The Three Mile Island Incident (TMI) in Pennsylvania, triggered by water pump failures and improper procedures, led to the evacuation of 144,000 individuals, including pregnant women and children, within a five-mile radius. Concern heightened within the community due to the expanding hydrogen bubble and looming threat of an explosion, resulting in the closure of schools until April 10. Subsequently, the TMI area experienced intermittent radiation releases, discovered in January 1980 that the incident narrowly avoided a meltdown by 30-60 minutes, released krypton gas from the containment structure of the damaged reactor, raised safety apprehensions regarding cleanup efforts, sparked conjecture about illnesses associated with the TMI event, and deliberated on reopening the unaffected reactor. The national media annually report on the TMI anniversary, while it remains a constant local news topic. Despite public health authorities' determination that radiation leaks didn't cause significant health issues, the community's

heightened stress raised concerns about potential mental health impacts.

9. REGULATORY AGENCIES [36- 39, 40]

Global Regulatory Agencies

Global regulatory agencies play a vital role in minimizing chemical hazards in various industries, including pharmaceuticals. These agencies are responsible for developing and enforcing regulations and guidelines aimed at protecting human health and environment from the risks posed by hazardous chemicals.

These organizations include:

- US Food and Drug Administration (US FDA).
- The Insecticides Act, 1968.
- The Environment Protection Act, 1986, India.
- Pest Management Regulatory Agency (PMRA), Health Canada.
- Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), United States.
- National Toxicology Program, United States.
- National Administration of Drugs, Food and Medical Technology, Argentina.
- The European Agency for the Evaluation of Medicinal Products.
- Federal Institute for Drugs and Medical Devices, Germany.
- Medicines and Healthcare Products

Regulatory Agency, United Kingdom.

- World Health Organization (WHO), Geneva, Switzerland.
- International Conference on Harmonization, Geneva, Switzerland.

Indian Regulatory Agencies

The Republic of India has promulgated several laws and regulations to exercise all the powers conferred by The Environmental Protection and Pollution Control Act and Rules. The measures shall be implemented and applied in all activities of the Environment Legislation Agency. The laws and regulations selected include:

- Drugs and cosmetics act, 1940.
- The Prevention of Food adulteration Act, 1954.
- Insecticides Act, 1968.
- The Water (Prevention and Control of Pollution) Act, 1974.
- Air (Prevention and Control of Pollution) Act, 1981.
- Narcotic Drugs and psychotropic substances Act, 1985.
- The Environment (Protection) Act, 1986.
- Manufacture, storage, and import hazardous chemicals rules, 1989.
- Hazardous wastes (management and handling) rules, 1989.
- Water Prevention and Control of pollution Act, 1974.

- Hazardous waste (management and handling) Rules, 1989.
- Manufacture, storage and import hazardous chemical Rules, 1989.
- Rules for manufacture, use, import and storage of hazardous microorganisms, genetically engineered micro-organisms or cells, 1989.
- Biomedical waste (management and handling) Rules, 1998.
- The recycled plastic manufacture and usage Rules, 1999.
- The ozone-depleting substances (regulation and control) Rules, 2000.
- The noise pollution (regulation and control) Rules, 2000.
- The batteries (management and handling) Rules, 2001.

Our standard of living has considerably improved through chemistry with different valuable items, but this has also provoked global environmental starvation and also the decline of non-renewable natural resources because it has provided us. Numerous toxins enter the food chain and degrade the ecosystem. Green chemistry and its principles can change some of these aspects and adverse effects; it is about sustainable development through design, development and green practices to restore growth. The ultimate objective would be to develop and design

unconventional artificial methods for critical commercial chemical compounds to prevent/reduce air pollution, which is certainly environmentally friendly.

CONCLUSION

Chemicals are frequently used by companies, but not all are safe due to their physical and chemical characteristics. The situation poses a significant threat to both workers and the environment, necessitating managers to navigate a complex set of laws and regulations. The 'Key to Safety' lies in the specification and implementation of adequate safety measures, with accurate and timely information being crucial for developing an effective chemical safety management system. Initiatives suggest creating regulations, conventions, and codes to address workplace chemical safety, requiring senior management commitment, consultative mechanisms, policy development, program implementation, and strategic integration. Chemical safety activities should be integrated into industrial system management functions, using contemporary risk management approach for handling hazardous chemicals in industries.

Developing safe chemical handling processes, including purchasing, inventory control, hazard communication, competency training, risk assessment, and systems for controlling

chemical risks, is crucial for maintaining safety and environmental sustainability. A risk management system for hazardous chemicals can ensure safe industries with minimal safety, health, and environmental risks.

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CONFLICT OF INTEREST

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