**Cl2 EXPOSURE: AN ANALYSIS OF RESPIRATORY HEALTH EFFECTS AND POTENTIAL THREAT OF CHEMICAL TERRORISM**

by

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**ABSTRACT**

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Elemental chlorine (Cl2) is a highly reactive toxic chemical. It is largely used for industrial purposes such as bleaching textiles and paper, manufacturing plastics such as PVCs, and disinfection of tap water. Extensive uses of Cl2 in industrial settings demand large quantities to be produced, transported and stored. Although rare, exposure to Cl2 generally occurs in occupational settings. Furthermore, exposure to Cl2 is known to affect the respiratory tracts. This is due to the reactive properties and slight water solubility of Cl2. When Cl2 reacts with water, i.e. moisture in the mucous membrane, it forms hypochlorous acid and hydrochloric acid. The reaction, along with subsequent biochemical reactions is thought to cause the respiratory effects such as: eye, nasal and throat irritation at low to mild exposures, chest pain, dyspnea and wheezing in moderate levels of exposure, and reactive airway dysfunction syndrome (RADS) and pulmonary edema in high acute exposure. Although exposures resulting in such symptoms are rare in the general population, Cl2 exposure remains to be significant to occupational health due to the large amounts used. Furthermore, potentials of accidental spills and tank ruptures during transportation can be fatal. Thus, Cl2 poses a significant public health concern. Use of Cl2 as a method of chemical terrorism is also of public health relevance as it threatens the safety and well being of the general population.

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# Introduction

Chlorine is a greenish-yellow gas often distinguished by its pungent, irritating odor.1It is primarily used as a bleaching agent in the paper and textile industries. Due to its oxidative properties, chlorine is highly reactive. When chlorine reacts with water, it forms hydrochloric acid (HCl) and hypochlorous acid (HClO).2 This reaction is used in a process called water chlorination—one of the most prominent methods of disinfecting tap water to kill bacteria and prevent waterborne diseases.3 Ironically, the same reaction below and subsequent biochemical reactions have been known to cause irritating and corrosive effects when the human epithelium (which contains moisture, i.e. H2O) is exposed to chlorine.4 Thus, posing a potential threat to human health. The formation of hydrogen chloride and hypochlorous acid as shown in the equation below.

Cl2+H2O🡪HCl+HClO

The name “chlorine” was designated to identify elemental chlorine (Cl2). However, it is often misused and many common chlorine compounds such as hydrogen chloride and sodium hypochlorite (NaClO, a common active ingredient found in household bleach products) are also colloquially called chlorine. Although chlorine is a significant component of these compounds, the chemical and physical properties vary from that of elemental chlorine and should be recognized as such. Elemental chlorine will be designated as Cl2 in this essay. The health effects of Cl2 are comparatively different from many of the compounds that contain chlorine. Exposure to chlorine typically occurs in occupational settings where the gas is used or produced, or during accidental spills and tank ruptures.

The health effects of Cl2 exposure depend on various factors including route, duration, and the concentration of exposures. While many of the effects of common Cl2 exposure are symptomatically brief and temporary, studies have found that high levels of exposure (i.e. due to accidental spills and tank ruptures during transportation) can be fatal and have debilitating health effects on the respiratory system.2

According to the National Institute of Health, respiratory diseases is the third leading cause of death in the United States.5 Thus, the association of Cl2 exposure and respiratory health effects is of interest to public health as Cl2 exposure-induced respiratory diseases can add to the national burden of respiratory disease in general. Furthermore, a compromised respiratory system can have a major impact on the quality and longevity of life. Additionally, Cl2 can potentially be used in chemical terrorism acts and warfare, posing a significant threat to the population.6

This essay is a literature review consisting of compilations of various research articles and reports from government agencies and organizations. It is intended to communicate to the general public, the extent of respiratory health effects caused by Cl2 exposure at various levels. Additionally, the aim of this essay is to serve as a basis for exposure assessment for potential threat of chemical terrorism as Cl2 is a highly reactive toxic element and has been used as a chemical weapon in various parts of the world.6

# Review

## Chlorine Properties

In its elemental state, chlorine is a diatomic gas of the halogen family with a density 2.5 times greater than air. It is naturally found in salt form (i.e. NaCl) and commercially produced by electrolysis of sodium chloride brine.2 It has a pungent, and distinctive odor similar to that of household bleach. This odor is discernable at around 0.32 ppm, which is less than the permissible exposure limit of 1 ppm.2 The chemical and physical properties of Cl2 are shown below. As a gas at room temperature, Cl2 can be stored and transported in pressurized liquid (amber-colored) form.2 Table 1 below displays a summary of the chemical and physical properties of chlorine.7

Table 1: Chemical and Physical Properties of Chlorine

|  |  |
| --- | --- |
| Atomic Symbol | Cl |
| Atomic Weight | 35.45 g/mol |
| Molecular Weight (Cl2) | 70.90 g/mol |
| Boiling Point | -33.97C |
| Melting Point | -100.98C |
| Density of Cl2 gas(at 0 C, 101.325 Pa) | 3.213 kg/m3 |
| Water Solubility (at 15.6 C, 101.325 Pa) | 8.30 kg/m3 |
| Vapor Pressure | At 0C—368.9 kPa At 25C—778.8 kPa |

Cl2 is nonflammable; however, it is very reactive and can be explosive when it comes in contact with substances such as: hydrogen, ammonia, acetylene, ether, turpentine, and finely divided metals. 7

## Naturally occurring chlorine

In the environment, Cl2 is naturally found at low levels in seawater aerosols.8 It is almost never found in its pure elemental form (Cl2), due to its reactivity towards both organic and inorganic compounds. Chlorine is typically found combined with sodium in the form of sodium chloride, but also found as carnallite (magnesium potassium chloride) and sylvite (potassium chloride).9 Cl2 is not known to be found in plants and soils; however Cl- (Chloride), can be found in soils. The concentration of chloride in soils is mainly determined by water flow, rainwater, sea sprays and air pollution.10 Chloride is also an essential micronutrient found in the cytoplasm of chloroplasts. 10

## Uses of Chlorine

Cl2 is among one of the highest volumes of chemicals produced in the United States.4 Compared to a global production of 56 tons per year,11 the United States produced 11.6 million tons of chlorine.12

### Industrial and Commercial uses

Cl2 is used as a disinfectant to kill bacteria during treatment of drinking water. It is also used to make various consumer products including paper, textiles, paint and plastics such as polyvinyl chloride (PVC)—a common plastic used in the manufacture of window frames, blood bags, and electrical wiring insulations among many.13, 14 An estimated 39% of chlorine produced is used to make PVC.15 About 3% of Cl2 is used to make solvents such as trichloroethane, commonly used in dry cleaning, and 16% of Cl2 is used to make inorganic compounds such as hydrochloric acid found in many cleaning agents and hypochlorite (household bleach). 15

### Chlorine, chemical warfare and terrorism

Chlorine gas was used as a chemical weapon in warfare dating back to World War I.16 A Jewish-German scientist, Fritz Haber, suggested chlorine gas could be used to “shorten the war”. 17 Haber gained recognition for his work after discovering the potential of synthesizing ammonia for fertilizer from nitrogen and hydrogen in a greater production of food supply during times of population growth. His method was subsequently used in large-scale crop productions, eradicating the fear of famine across the world, introducing the phrase “bread in air”.17

Recognizing that the same process had a potential for making explosives for the military, Haber began to experiment with chlorine gas. His method of Cl2 gas production was first used during the second battle of Ypres in 1915, which killed and injured thousands.17 Ironically, Haber’s work was further developed into the Zyklon B process, which was used by the Nazis to kill millions of Jews in the Holocaust, including his own extended family.17

In recent years, Cl2 was used in terrorist attacks in Iraq, targeting civilians and police forces.18 Bombs were attached to chlorine cylinders and detonated in these attacks. According to United Nations Monitoring, Verification, and Inspection Commission, at least 10 attacks involving chlorine were reported to have occurred in Iraq since June 2007. 18

### Chlorine and Pharmaceuticals

Chlorine is a strong oxidizing agent and plays a significant role in substitution reactions in organic chemistry, and many common solvents are chlorinated. An estimated 93 percent of pharmaceuticals use Cl2 and chlorine compounds in their manufacturing processes.19 Chlorine chemistry has been used to manufacture drugs to treat conditions and diseases such as: diabetes, cancer, anemia, stomach ulcers, asthma, high blood pressure, high cholesterol, depression and inflammation.19 Uses of chlorine can serve as an intermediate to facilitate the synthesis of the drug (i.e. the use of hydrochloric acid solution to control pH during manufacturing process or the use of chlorinated solvents to separate or purify agents.19

## Releases of Cl2 and its Environmental Impact

Cl2 may be released into the air by industrial facilities where it is is used or produced. It may also be released due to accidental spills and tank ruptures. In 2006, an estimated 5,050,000 pounds and 254,000 of Cl2 were released into air and water respectively by 915 manufacturing facilities.20 Furthermore, releases to soil were reported to be 291,000 pounds. Despite multiple reports of chlorine releases, very few studies have examined the effects of Cl2 exposure on plant life. One study examining the effects of high acute exposure to Cl2 gas on the foliage of deciduous and coniferous species found that foliar injury was most apparent within 100 m from the source of a Cl2 spill.21 Moreover; the study found that exposure to Cl2 also resulted in water loss and decreased photosynthetic ability of the plants.21

When Cl2 is released into water, it immediately reacts to form hydrochloric acid and hypochlorous acid; for this reason, no information on the effects of Cl2 on aquatic life was reported. Similarly, Cl2 is too reactive to be found in soil. It is expected to both volatilize into the air and form a greenish- yellow gas cloud and react with organic and inorganic compounds in the soil.20 Cl2 released into water and soil is not known to have a direct effect on aquatic life or microbial life in soil. However, the reactions that occur when Cl2 is introduced to water bodies and soil may alter the pH, and effect the ecosystems of the respective organisms.

# Human Exposure

Human exposure to Cl2 can occur in occupational settings during the manufacturing processes. Potential for high levels of chlorine exposure through accidental spills and tank ruptures exists in these settings due to the volume of chlorine used or produced. Residents living near these industries may also be exposed to chlorine.

Household exposure to chlorine gas can occur when cleaning products containing hypochlorite such as bleach (NaClO) mixed with other household acids.2 For instance, when hypochlorite, found in household bleach is mixed with household acids such as hydrochloric acid (HCl)—found in toilet cleaners, Cl2 gas is formed.22 The equation below shows the reaction between Sodium hypochlorite and Hydrochloric acid.

NaOCl*(l)* + 2HCl*(l)* 🡪 Cl2*(g)* + NaCl*(l)* + H2O*(l)*.

## Routes of Exposure

Methods of exposure to Cl2 include inhalation, skin/eye contact, and ingestion. Inhalation is the most common method of exposure and can cause various degrees of effects from persistent coughing to pulmonary edema, depending on the concentration of Cl2.1,4

Generally, skin or eye damage results from direct contact with concentrated chlorine, chlorine compounds, and concentrated chlorine vapors. At low concentrations, Cl2 exposure may result in eye and skin irritations.2, 4 Exposure to high concentrations can cause severe chemical burns, and ulcerations similar to frostbite.2,4 Furthermore, dermal exposure can result in redness, pain and blisters at high concentrations. Exposure to the eyes can cause redness, pain and burning sensation in the eyes and cause rapid blinking and tearing of the eyes.2 Ingestion is the least likely method to occur but if chlorine products are ingested, corrosive effects can occur in the gastrointestinal tract.2

## Health Effects

Health effects mostly occur in the respiratory tract and eyes. This is due to the moisture on the mucous membranes of the respiratory tracts and the eyes.4 The mechanism for this reaction is described in the following section. The skin is less likely to be exposed as it lacks the moisture of mucous membranes.4 Health effects due to chlorine depend on the concentration, duration of exposure, and individual susceptibility. Chlorine is classified as non-carcinogenic.23 No significant results were found in animal studies that evaluated reproductive and developmental effects of chlorine exposure.24 A brief summary of health effects at various levels of exposure is shown below. 2,4

Table 2 Health effects at various exposure levels

|  |  |
| --- | --- |
| Exposure Level | Health Effects |
| 0.1-3 ppm | Odor Detection |
| 1-3 ppm | Mild mucous membrane irritation; can be tolerated for up to 1 hour |
| 5-15 ppm | Moderate mucous membrane irritation |
| **Table 2 Continued** |  |
| 30+ ppm | Immediate substernal chest pain |
| 40-60ppm | Development of toxic pneumonitis, acute pulmonary edema |
| 400+ ppm | Fatal if exposed beyond 30 minutes |
| 1000+ ppm | Death within few minutes |

### Development of Health effects

Chlorine is known for its irritant properties which affect the eyes, skin and the respiratory system. Health effects caused by chlorine are related to its oxidative and slight water-soluble properties.4,25 When the human epithelium is exposed to Cl2, the gas reacts with moisture and other constituents in the airway tract (i.e. reaction of Cl2 and H20). This reaction is believed to yield the toxic effects of Cl2 exposure.4,25

Inside the respiratory tracts, these reactions allow Cl2 to cross the cell wall and further generate oxygen free radicals and other reactive oxygen species (ROS). Subsequently, ROS can react and form species such as: NO2, NO3, hydroxyl radicals (OH•), nitryl chloride (ClNO2) and penetrate further into the lungs causing airway injury, edema, inflammation, immediate airway constriction, and persistent airway reactivity.4,25

## Epidemiological and Animal studies

### Low and moderate acute exposure

Low to moderate concentration exposures to Cl2 occur within a range of 1 to 15 ppm. Symptoms due to low acute exposure include: eye tearing, involuntary blinking, mucous membrane irritation i.e. nose and throat.2 Exposure to moderate levels of chlorine can result in dyspnea, chest pain, sore throat, eye irritation, redness, and conjunctivitis.25

### High acute exposure: Histopathological effects of acute exposure in Sprague-Dawley rats

Health effects resulting from high concentrations of chlorine include asphyxia (due to chlorine’s high density compared to air and lack of ventilation), respiratory failure, pulmonary edema, and cardiovascular effects such as tachycardia. Reactive airway dysfunction syndrome (RADS), acute pulmonary hypertension, cardiomegaly, acute lung injury (ALI), pulmonary vascular congestion, acute respiratory distress syndrome, acute burns of the upper and lower airways, and death are also known health effects caused by exposure to high concentrations of chlorine. 26

In this study, Demnati et. al examined the effects of exposure to various levels of chlorine on airway mucosa and lung parenchyma in hopes to develop an animal model. Seventy-four Sprague-Dawley rats were divided into groups and exposed to air (as a control), and various concentrations of chlorine at 50, 100, 200, 500, and 1500 ppm for 2 to 10 minutes. Assessments were conducted after exposure at: 1, 3,6, 12, 24, and 72 hours. The results of this study indicated that low concentrations of up to 500 ppm at any duration of time did not induce any significant histological effects.25 However, perivascular edema and mild focal inflammation were observed in rats that were exposed to 1500 ppm for 2 minutes. In an assessment 1 hour after exposure, airspace and intestinal edema were observed in the same group of mice. Symptoms of edema began decreasing in assessments conducted between 6 to 24 hours after exposure.26

### Experimental Study: Long-term effects in rats after acute exposure

Histopathological effects of high acute exposure (1330 ppm of chlorine gas) 45 days after exposure were assessed in Sprague-Dawley rats. Two groups of rats were examined; one group of rats (group I) was examined immediately after exposure, the second group of rats was examined 45 days after exposure (group II). Both groups were compared to an unexposed group.27

Histopathological examination of group I rats showed a development of eosinophilic liquid accumulation in alveoli and bronchi, diffuse intra-alveolar edema, vascular congestions and severe perivascular edema. Group II rats, examined 45 days after exposure, did not display any signs of edema in the histopathological assessment. However, interstitial fibrosis and thickening of the alveolar septa due to thickening of the basement membrane were observed.27 The results of this study suggest that health effects seen immediately after acute exposure to chlorine dissipate over time but histopathologic damages do develop.27 In application to human exposure, those exposed to high concentrations of chlorine gas should be followed up to assess any further damage that may have occurred.

### Chronic exposure: Repeated exposure to chlorine gas during pulp and paper mill renovations

A study by Bherer et al examined the prevalence of persistent respiratory symptoms and bronchial hyper-responsiveness due to RADS (Reactive Airway Dysfunction Syndrome).28 The subjects in this study were construction workers exposed to chlorine gas during a renovation process to a pulp and paper mill. The study identified individuals who indicated they had persistent respiratory symptoms based on a questionnaire given 18 to 24 months after exposure and subsequently examined their health conditions. A total of 71 subjects qualified to be examined and spirometry was utilized for further assessment and analysis of health conditions. The results of this study indicated that 16 subjects showed evidence of bronchial obstruction and 29 displayed bronchial hyper responsiveness.28

### Accidents

In 2005, a train derailment accident resulted in a tank rupture that spilled 40 to 60 tons of chlorine across the premises of a textile mill in Graniteville, SC. Many victims developed severe airway inflammation and acute respiratory distress; wheezing was a common symptom.29 A total of 597 people were hospitalized. Ocular problems were observed in about 17% of these hospitalized subjects and 31% complained of cardiac symptoms. A total of 9 deaths were observed.29 The primary cause of death was asphyxia in those who died at the scene. This is due to the density of chlorine, which allows it to stay closer to the ground and spread across to the surrounding areas. Other causes of death include respiratory failure, pulmonary edema, and tracheal and bronchial erythema.29

### Long-term effects of accidental high exposure

In 1990, Schwartz et al examined the pulmonary function of 20 individuals who were accidentally exposed to chlorine 12 years prior to the individuals’ participation in the study.30 Initial records of pulmonary function tests one day after the accident showed high prevalence of airflow obstruction and air trapping. The study was able to test 13 out of the 20 subjects and found that airflow resistance persisted over the years, but symptoms of air trapping had dissipated.30 A pattern of low residual volume of the lungs was also seen during the study. Furthermore, 5 of the 13 individuals displayed airway reactivity followed by inhalation of methacholine—a compound used in assessing the presence of respiratory illnesses such as asthma.30 The results of this data suggest that exposure to high acute concentrations of chlorine may cause low residual volume and associated pulmonary conditions.

## Antidotal agents

Treatment for chlorine exposure is generally symptomatic, consisting of decontamination, humidified supplemental oxygen, and nebulized β-agonists for bronchospasm.31 A few studies examined sodium bicarbonate as a treatment for RADS due to chlorine gas inhalation. This is a plausible use of sodium bicarbonate as it is known to be used in acid neutralizations.31 In a study examining the treatment of acute chlorine gas inhalation, nebulized solution of 3.75% sodium bicarbonate was used to treat symptoms of cough, chest pain and shortness of breath in three patients exposed to chlorine gas. The patients displayed a relief in symptoms after the treatment and no future development of symptoms were observed.31

Moreover, in an observational study of 14 subjects, the use of 8.4% nebulized sodium bicarbonate solution after chlorine inhalation displayed a reduction in chest pain throat irritation and coughing.31 However, multiple studies showed conflicting results whether or not sodium bicarbonate is an effective antidote to chlorine exposure.31 Thus, the use of nebulized sodium bicarbonate solution should be further evaluated for safety and effectiveness of treatment.

## EPA Regulations

The table below displays a summary of regulatory and advisory values for chlorine inhalation exposure in occupational settings by various government sectors and organizations including: National Institute of Occupational Safety and Health (NIOSH), American Industrial Hygiene Association (AIHA), Occupational Safety and Health Administration (OSHA), and ACGIH, American Conference for Governmental and Industrial Hygienists.32

Table 3 Regulatory limits to chlorine inhalation exposure32

|  |  |
| --- | --- |
| ***Agency*** | ***Advisory Values*** |
| NIOSH IDLH immediate danger to life or health | 29 mg/m3 |
| AIHA ERPG2: maximum concentration almost all individuals can be exposed to up to one hour without enduring irreversible or serious health effects. | 9 mg/ m3 |
| OSHA and ACGIH ceiling: concentration that should not be exceeded at any given time during work  AIHA ERPG1: maximum concentration below which almost all individuals can be exposed to one hour without experiencing health effects that are no more than mild transient adverse health effects | 3 mg/ m3 |
| ACGIH TLV and NIOSH ceiling: concentration that should not be exceeded at any given time during work exposure. | 1.5 mg/ m3 |

Incidents of chlorine exposure have been reported in the past. However, the occurrences are still rare. A plausible reason for such low prevalence may be due to the implementation of occupational safety standards. Moreover, OSHA has further occupational exposure restrictions that only allow a 1-ppm exposure limit for short-term exposure of 15 minutes and no more than 0.5 ppm for long-term exposures of over 15 minutes.33

# Public health Concern: A potential THREAT OF CHEMICAL TERRORISM

## Epidemiology of chlorine exposure

In 2014, the American Association of Poison Control Centers (AAPC) reported a total of 3604 cases of chlorine exposure and 1998 cases of chlorine gas exposure caused by mixing household acids with hypochlorite.34 The following table displays a breakdown of reasoning and severity of these reported cases.

Table 4: Reported cases and health effects due to chlorine gas exposure and chlorine gas exposure due to mixing of hypochlorite and household acids.34

|  |  |  |
| --- | --- | --- |
|  | Chlorine gas exposure | Chlorine gas exposure due to mixing of hypochlorite and household acids |
| Total | 3604 | 1998 |
| **Reason**  Intentional  Unintentional  Other  Adverse reaction | 3430  102  13  50 | 1907  90  1  0 |
| **Health Effects**  None  Minor  Moderate  Major  Death | 268  1287  453  8  2 | 206  719  264  2  0 |

\*Adverse Reaction: Unwanted effects due to an allergic, hypersensitivity, or idiosyncratic response to a substance other than drug or food.   
\* Minor: minimally bothersome signs and symptoms  
\* Moderate: more prolonged, or more systemic in nature than minor symptoms.   
\* Major: signs and symptoms were life-threatening or resulted in significant residual disability or disfigurement

While the health effects at higher levels of Cl2 exposure can be life threatening, the prevalence of such exposure and outcomes is often rare. The majority of the cases reported by the AAPC in both categories (chlorine gas exposure and chlorine gas exposure due to mixing of hypochlorite and household acids) resulted in minor health effects. The signs and symptoms were minimally bothersome i.e. limited to the mucous membranes and skin. A total of 10 cases in 2014 resulted in major health outcomes that were life threatening.34 Most household products containing hazardous chemicals are labeled according to the EPA and FDA regulations, which help enhance safety of such products. These incidences and health outcomes of chlorine gas exposure are so low compared to respiratory diseases and deaths caused by other factors such as smoking—a pressing public health concerns, that chlorine gas exposure may not be considered a significant factor in the burden of respiratory diseases.

In fact, cigarette smoking is the leading cause of preventable death and results in about 480,000 deaths per years including 42,000 from second-hand smoking while only 2 deaths were reported in 2014 due to chlorine gas exposure.34,35 Despite the low prevalence of deaths, health effects such as RADS and pulmonary edema due to chlorine exposure at extremely high concentrations remain life threatening. These health effects may not be significant enough to add to the respiratory disease burden but, they are still severe and life threatening. Despite the rarity in occurrences of Cl2 exposure, research in health effects caused by Cl2 exposure can still be life threatening and should be further explored as very few studies have been conducted on the long term health effects. Moreover, antidotal methods should continue to be studies, as very few studies have examined such methods.

## Policy Implementation

Chemical industries have recognized their potential vulnerabilities to terrorist attacks and have complied with policies under the Responsible Care Security Code.36 This security code requires chemical facilities to complete vulnerability assessments, physical security enhancements, and independent third party audits of their facilities, and employee trainings and drills.36 Almost 98% of chlorine producers and 100% of chlorine packagers in the United States follow this Code. 36

Furthermore, emergency preparedness in an event of an accident is enhanced by regulations implemented by the EPA. The Emergency Planning and Community Right to know Act (EPCRA), requires all facilities that use or store hazardous chemicals which include chlorine, to maintain a material safety data sheet (MSDS).37 These facilities are required to submit MSDSs to the local fire department, the Local Emergency Planning Committee and the State Emergency Response Commission.37 Furthermore, this information of chemicals at facilities can also be made available to the public at the owner’s will.

Availability of such a list of chemicals can have juxtaposing effects. On one hand, the information can allow residents to be aware of their surroundings and make informed decisions in regards to where they choose to live. While on the other hand, such information can make terrorist attacks more feasible. Knowing the location of a hazardous chemical storage can make it easier for terrorists to attempt to access the chemical.

Implementation of the EPCRA regulations and policies from Responsible Care Security Code, along with OSHA workplace exposure limits and safety standards, has strengthened occupational safety and emergency preparedness—should an *accident* occur in these facilities. However, these preparations and guidelines cannot prepare a chemical facility for unforeseen acts such as terrorist attacks. Thus, the greatest threat of chlorine exposure does not stem from occupational or household uses of chlorine, rather, it stems from the potential uses in chemical terrorism.

### Rail shipment safety

Rail shipment is an ideal method of transportation for hazardous materials and toxic chemicals such as chlorine due to the feasibility in transporting large quantities required for industrial uses. Rail accidents involving chlorine are extremely rare yet destructive. The Pipeline and Hazardous Material Safety Administration (PHMSA) has implemented regulations that pertain to speed restrictions and routing of tank cars carrying such chemicals. All tank cars containing hazardous material are required to follow a 50 mph speed limit.38 A 40 mph restriction is implemented in High Threat Urban Areas (HTUA) and in areas with a population greater than 100,000.38 Although these requirements are in place, no methods of tracking whether or not the tank cars are following the speed limit have been reported to be used. Perhaps, installing a tracking device that can locate the tank cars and report the speed can help reduce the possibility of speeding and further reduce rail accidents involving such toxic chemicals.

Tank cars must meet respective Federal Railroad Administration (FRA) standards based on hazardous chemical being carried.38 PHMSA has also been working on improving tank car design standards to enhance transportation safety. Standards for these tank cars have been set to enhance durability and resistance to punctures and ruptures in an event of an accident.38

Furthermore, no new reports of ruptures in tank cars containing hazardous materials such as chlorine have been reported since 2005. Occurrences of rail accidents of hazardous material containing tank cars have always been rare; it is possible that the implementation of these policies strengthened the safety of tank cars and minimized the risk of tank ruptures and spills during shipment.

While the durability of tank cars may be adequate enough to withstand punctures, tank car safety during transportation can be further strengthened with implementations of tracking devices that can report location as well as traveling speed to prevent drivers from speeding.

The problem however, continues to remains in the vulnerability of terrorist acts due to the open nature of railroad routes. These freight trains pass through high threat urban areas (HTUA) that are densely populated.38 Furthermore, idling time also increases the potential for terrorists to access large amounts of hazardous chemicals. A reduction of idling time of hazardous chemical tank cars in urban areas and rerouting such tank cars away from densely populated areas can reduce the impact in an event of such terrorist act. However, vulnerability of Cl2 being used as a chemical weapon continues to persists.

### Chlorine and chemical terrorism

In recent years, multiple attacks in Syria have been reported involving the use of chlorine as a chemical weapon against civilians. The consequences of the attacks were so deadly and that the UN Security Council condemned the use of chlorine as a chemical warfare weapon.39Although it is unclear whether the attacks were carried out by the government or terrorist, Cl2 has been reported to have been used in the rebel held northern Syria in 18 different cases.39 Despite the condemnation of Cl2 as a chemical weapon, Cl2 was still accessed and used as a weapon.

In the U.S, the Department of Homeland Security implemented anti-terrorism standards to protect chemical facilities. Under these policies, all chemical facilities are required to report storage and quantities of certain chemicals (including chlorine) and complete a preliminary risk assessment.40 Based on this preliminary assessment, the Chemical Facility Anti–Terrorism Standards (CFATS) Program identifies high-risk chemical facilities and requires them to maintain appropriate security standards based on potential risks specific to the facilities.40

These rules and regulations are meant to offer protection against potential terrorist acts in chemical facilities. Implementation of these policies may have strengthened the future security of hazardous chemicals such as chlorine, to reduce the threat of chemical terrorism; however, terrorist attacks can be instigated by workers within the facility. Although no known terrorist acts involving security breach of Cl2 chemical facilities have been reported in the U.S it may only be a matter of time before an occurrence of a terrorist attack. Furthermore, severe health effects begin to occur after exposure to 30 ppm (30 mg/L) of Cl2 or more, indicating that it does not require extremely large quantities to cause significant health effects. Accessing such quantities of Cl2 can be done by chemical facility workers without being noticed. Thus, thorough background checks and additional psychological evaluations of all chemical facility workers should be required to assess workers’ personalities, behaviors and capabilities to work in a high risk facility.

## Discussion

The potential for Cl2 as a chemical threat will continue to persist due to its chemical properties and the effects on human health. The possibility of Cl2 as a chemical weapon remains a concern despite implementations of the current safety and security standards in chemical and industrial facilities. Vulnerability continues to persist during transportation where Cl2 containing tank cars may remain idle, increasing the chances of theft by terrorists. Accidents during transportation of Cl2 are often rare but the health effects endured after exposure can be debilitating. Safety and security measures during transportation should continue to be enhanced through implementation of policies.

# Conclusion

Chlorine is a highly toxic element and the resulting health effects are irrefutably destructive. Exposure to toxic levels of chlorine is often accidental and rare and tends to occur during transportation and in industrial settings. Immediate effects of chlorine exposure are known to be prominent in the respiratory system. These health effects can be fatal and burdensome. However, because the occurrences of such incidences are often so rare, chlorine exposure may not be of substantial concern to the general public. Greater potential of exposure exists in occupational settings; however, facility safety guidelines and EPA regulations are in place to protect workers from such toxic exposures.

A greater focus of efforts and time should be invested in the treatment of chlorine toxicity. Currently, treatment for chlorine exposure is mostly supportive and symptomatic and very few studies aimed at antidotal methods have been conducted. Future studies invested in better medical treatment for high concentration chlorine exposure can be beneficial to help reduce the potential for any further long-term health effects caused by chlorine exposure.

What raises an equally grave concern is the potential use of chlorine in chemical terrorism and the possible access to chlorine during transportation. Although no such terrorist acts were reported to have occurred in the United States, the potential of such acts continues to remain high due to the nature of the railway system and routes used to transport toxic chemicals such as chlorine.

Banning chlorine is highly unlikely due to its multitude of uses in manufacturing commercial and medicinal products. It is in the best interest of national security to direct a focus of efforts in emergency preparedness training of employees and security personnel for accidental cases or unexpected occurrences such as acts of chemical terrorism.

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