# Inherent Safety and Chlorine in Water Treatment

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"On my honor, as an aggie, I have neither given nor received unauthorized aid on this academic work."

## Executive Summary

Chlorine has been used for water treatment purposes for more than one hundred years. The simplicity and effectiveness of using chlorine and its derivatives for water treatment is one of the wonders of modern chemistry: it is cheap, it is safe, and it works. Chlorine has uses on water intake structures, for the removal of aquatic organisms, for pre-filtration, to kill bacteria and for water disinfection. The gas has a greenish-yellowish color and has a molecular weight that is two and a half times larger than that of air. In its gaseous form, chlorine is extremely toxic and dangerous. It also has a very high coefficient of expansion. For this reason, all chlorine containers' volume must not be filled up past eighty five percent of their capacity. Chlorine gas is fed into the water treatment system under vacuum conditions. Chlorine tanks have an automated system of regulators, feed equipment and vacuum ejectors. Piping connections must be sealed with proper pipe thread compound and compression fittings must be sealed with a new lead washer. Also, chlorine gas scrubbers should be installed in any facility that uses chlorine gas. The Environmental Protection Agency (EPA) requires wastewater plants which store two-thousand five-hundred pounds or more of chlorine gas to conduct a risk management plan. Risk reduction begins with using the smallest cylinders possible of chlorine gas for the application. Water treatment plants can manifold as many ton containers as necessary while controlling for leaks at each individual container and throughout the entire system. In addition, the water plant should be located as far out of the city as possible, downwind of the prevailing winds. Booster systems at strategic locations can be placed. The Pasquill-Gifford model is a very good way to estimate the concentrations of a release at different distances from the source. However, a better

model to use would be the Britter and McQuaid model for dense gases. Risk assessment software such as PHAST provides planners and retrofitters with a tool to determine various levels of risk. The example used about Ras-Laffan was simulated using PHAST for the three cases involved. The companies at Ras-Laffan assume that the wind direction from that region will always be North-West. If that were true, then the results from PHAST show that there would be no risk of the leak reaching any of the surrounding cities. The rupture of a one- ton cylinder could potentially produce a cloud one mile high by a half- mile wide by one mile long of toxic mustard gas that will kill everything in its wake. A train in Ontario derailed and a tank car of chlorine gas ruptured; if there had not been a large propane fire funneling the heavier-than-air mustard gas upwards into the atmosphere, many thousands of people in the city of Mississauga might have died. Although chlorine is by far the cheapest chemical to use for water treatment, the most widely accepted, and has the fewest risks to public health, other chemicals should also be investigated.

## Table of Contents

## List of Figures

## Introduction

Chlorine has been used for water treatment purposes for more than one hundred years. Out of the sixty three thousand water treatment plants in the U.S. and in Canada, over ninety-eight percent of the plants utilize chlorine or its derivatives (Whitfield and Brown, 2009, para. 5; para. 9). The simplicity and effectiveness of using chlorine and its derivatives for water treatment is one of the wonders of modern chemistry: it is cheap, it is safe, and it works. Chlorine derivatives such as gaseous chlorine and sodium hypochlorite are used for larger applications, and even dry calcium hypochlorite briquettes (molded blocks of chlorine) are finding their way into small operations beyond the usual use in swimming pools and well heads (Brennan, 2006). Background information on the uses and properties of chlorine will be discussed, as well as the steps used to reduce harm from a chlorine leak. In addition, the Pasquill-Gifford dispersion model and the PHAST simulation program will be mentioned. Finally, the implications of real-life chlorine incidents will be discussed, as well as alternatives to using chlorine for water treatment.

## Background

### Uses of Chlorine

Chlorine has a variety of uses in a water treatment plant. It is used on water intake structures (structurez of flowing water through pipes or waterways) for the removal of aquatic organisms, as pre-filtration to oxidize metals such as iron and manganese for removal, and to kill algae and bacteria. Please refer to Appendix 1 for a more comprehensive list of pathogens to which chlorine is applied. Most importantly, when used for the disinfection of drinking water, its residual effects continue on through the system preventing further contamination once the water leaves the treatment plant.

## Properties of Chlorine

In 2006, John Volbeda presented a background discussion of chlorine chemistry. Basically, when chlorine gas is dissolved in water, hypochlorous acid is created. Combining sodium hypochlorite (bleach) with water produces hypochlorous acid and the hypochlorine ion. The volatile nature of the chlorine molecule contributes to both its disinfection power and its danger as a chemical. The chlorine atom does not care where it gets its eighth electron and will literally rip it out of any constituent in the water, which include bacteria and viruses. Chlorine has the ability to combine with anything, and the combination can be toxic to bacteria and viruses. Even though the disinfection process is slowed down when using a combined chlorine product or byproduct for disinfection, disinfection still occurs due to the toxic nature of chlorine.

Chlorine has many other properties that distinguish it from other elements. It is a greenish-yellowish gas that has a molecular weight of two and a half times greater than that of air. In its gaseous form, chlorine is extremely toxic and dangerous. Kenneth D. Kerri succinctly presents the dangers of chlorine gas:

> “It has a very high coefficient of expansion. If there is a temperature increase of 50 degrees, the volume will increase from 84-89 percent. This expansion could easily rupture a cylinder or line full of liquid chlorine. For this reason all chlorine containers must not be filled to more than 85 percent of their volume. One liter of liquid chlorine can evaporate and produce 450 liters of chlorine gas” (Kerri, 1989, p. 261).

## Steps to Reduce Harm from Chlorine Leak

Because of the dangerous properties of chlorine, guidelines are set forth for the safe handling of chlorine gas in a treatment plant (Kerri, 1989). Chlorine gas is fed into the water treatment system under vacuum conditions. This is because chlorine is a strong oxidizer that can react with other materials such as ammonia which in turn can become very explosive. Chlorine tanks have an automated system of regulators to reduce pressure from tanks, feed equipment to accurately measure feed rate, and vacuum ejectors to deliver the chemical into the receiving water. Piping connections must be sealed with proper pipe thread compounds (gray paste for pipe joint threads) to ensure that pipe joints are not subject to chlorine attack, and compression fittings must be sealed with new lead washers. When the system is first started, and each time an empty chlorine tank is switched for a new one, a simple ammonia check should be performed. Ammonia and chlorine combine to create a white smoke, indicating that a leak is present. At each point in the process, automatic and manual overrides (where the system that used to be controlled automatically becomes controlled manually) exist if a leak is detected at any point.

Also, chlorine gas scrubbers should be installed in any facility that uses chlorine gas. These scrubbers are designed to handle the volume of one tank in the event of a rupture. A leak detection system turns the scrubber on when a leak is detected, and the system scrubs one tank-volume worth of chlorine gas into a sodium hydroxide solution. The resulting combination of chlorine and sodium hydroxide is a ten percent bleach solution which can then be used as a liquid form of chlorine.

Because of the hazards and risks that are associated with chlorine in the water treatment industry, there are many things that a risk assessment should consider when planning a water treatment facility that uses chlorine. The Environmental Protection Agency (EPA) requires wastewater plants which store two-thousand five-hundred pounds or more of chlorine gas to conduct a risk management plan (Stephenson, 2007). Risk reduction begins with using the smallest cylinders possible of chlorine gas for the application. Using one hundred and fifty pound cylinders or less minimizes the risk of tank rupture. However, one liter of chlorine gas will expand under pressure to four hundred and fifty liters; a rupture will make a very large cloud of toxic gas, but it will be the smallest compared to the size of the container used. As demand and facility size increase, cylinders become manifolded together; a one hundred and fifty pound cylinder is not appropriate for most municipal water treatment applications. A majority of water treatment plants use one-ton cylinders joined together.

Also, extreme care is taken at every point in the system to ensure that a tank rupture or leak does not occur. Omaha Metropolitan Utilities District recently redesigned the municipal water treatment system to provide for the efficient use of liquid withdrawal methods from several cylinders. Rather than expanding the scrubber system, they installed actuators (devices that convert energy from air or liquid to motion) on each of the twenty four ton tanks in the facility (Koenig and Slaydon, 2008). Using systems based on this model, water treatment plants can manifold as many containers as necessary while controlling for leaks at each individual container and throughout the entire system. Daily, weekly and monthly, maintenance checks and safety drills of manifolded systems are absolutely necessary in conjunction with using technology to automatically control for accidents.

When using gas chlorination, the location of the water treatment plant is of extreme importance. The water plant should be located as far out of the city as possible, downwind of the prevailing winds so that should a rupture occur and the scrubbing system fail, the prevailing winds will dissipate the killing cloud of mustard gas away from population centers. Planners must not only assess current risk to the population, but must also account for planned growth in a city. It is possible that with proper planning and safety protocols, gas chlorination water treatment facility can be placed in the middle of a population center (although this situation is not ideal).

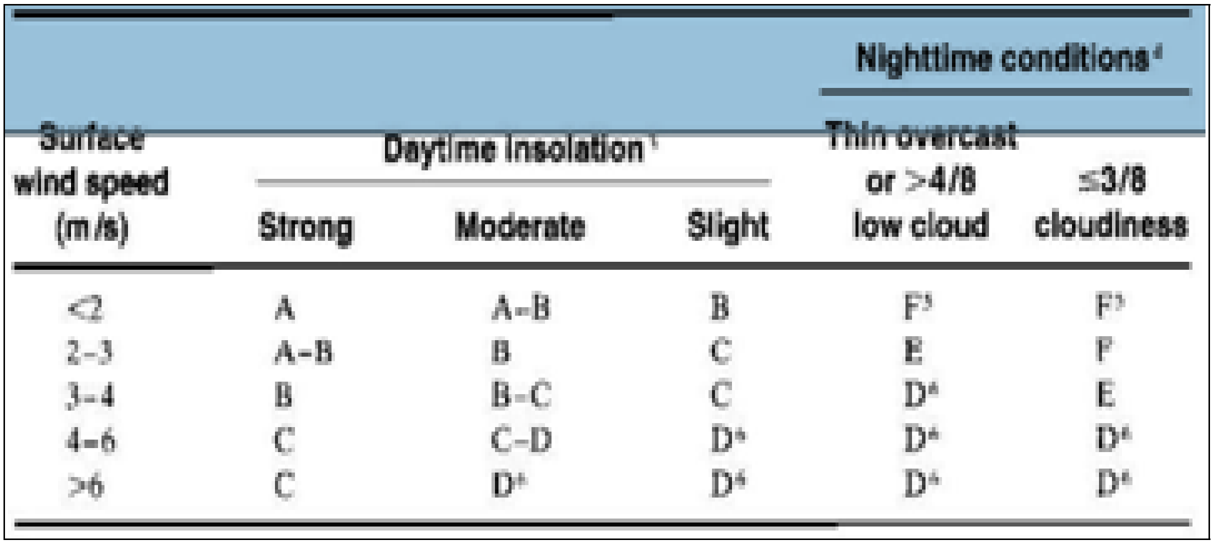
In addition to sizing and locating a municipal water treatment plant correctly, booster systems at strategic locations may also be helpful in reducing risks (Tryby, Boccelli, Uber, and Rossman, 2002). Booster systems are a common practice, but protocols regarding their safety and efficiency are not always rigorous. A network beginning at the main treatment plant pipes treated water to various parts of the system, where population demands determine the need for booster nodes. A model such as this spreads out the risk of chemical spills, reduces the need for onsite chemical storage at any one location, and allows for the more economical use of alternative technologies. On the downside, booster stations require more man hours for maintenance and inspections, and more equipment overall to operate a large system of nodes.

## Pasquill-Gifford Dispersion Model

The Pasquill-Gifford model is a very good way to estimate the concentrations of a release at different distances from the source. This model can be considered fairly accurate only for neutrally buoyant gases. The two main types of vapor clouds used are the plume and puff model. A puff is when a fixed amount of gas is leaked momentarily from a source. A plume is when a constant amount of material is released continuously from a source (Crowl D. and Louvar, J., 2002).

In order to find the concentrations leaked, the Pasquill-Gifford model uses a term called a dispersion coefficient, which is the standard deviation of the concentration downwind of the source in the x, y or z directions. The formula for the dispersion coefficient is the following: $\sigma_x^2 = \frac{1}{2} < C >^2 (ut)^{2-n}$

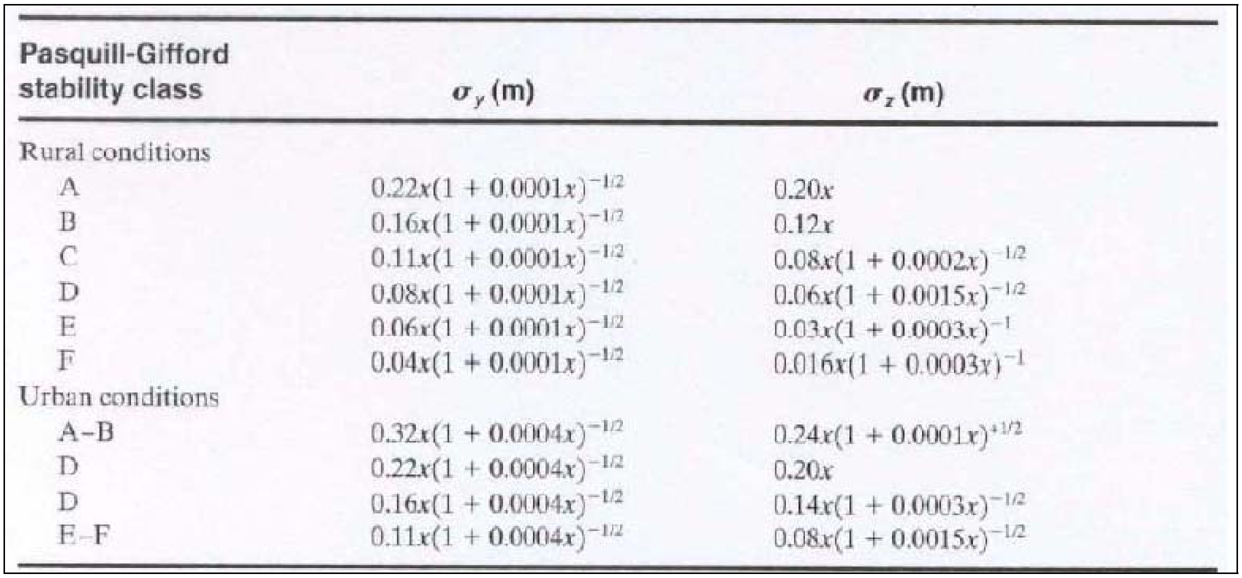
Insolation refers to incident solar radiation, which can be classified as strong, moderate or slight. Depending on the wind speed, the classes of insolation can be divided into A, B, C, D, E and F where class A is exceptionally unstable, class B is somewhat unstable, class C is a little unstable, class D is neutrally stable, class E is a little stable and class F is somewhat stable. Figure 1 gives the different classes from A-F of the weather for different wind speeds and insolation conditions (Crowl D. and Louvar, J., 2002).



| Surface wind speed (m/s) | Daytime insolation$^1$ | | | Nighttime conditions$^2$ | |
|---|---|---|---|---|---|
| | Strong | Moderate | Slight | Thin overcast or >4/8 low cloud | ≤3/8 cloudiness |
| <2 | A | A–B | B | $F^3$ | $F^3$ |
| 2–3 | A–B | B | C | E | F |
| 3–4 | B | B–C | C | $D^4$ | E |
| 4–6 | C | C–D | $D^4$ | $D^4$ | $D^4$ |
| >6 | C | $D^4$ | $D^4$ | $D^4$ | $D^4$ |

Figure 1: Atmospheric stability classes (Crowl D. and Louvar, J., 2002).

After the atmospheric stability class and the distance downwind are known, the dispersion coefficients $\sigma_y$ and $\sigma_z$ can be calculated from Figure 2.



| Pasquill-Gifford stability class | $\sigma_y$ (m) | $\sigma_z$ (m) |
|---|---|---|
| Rural conditions | | |
| A | $0.22x(1 + 0.0001x)^{-1/2}$ | $0.20x$ |
| B | $0.16x(1 + 0.0001x)^{-1/2}$ | $0.12x$ |
| C | $0.11x(1 + 0.0001x)^{-1/2}$ | $0.08x(1 + 0.0002x)^{-1/2}$ |
| D | $0.08x(1 + 0.0001x)^{-1/2}$ | $0.06x(1 + 0.0015x)^{-1/2}$ |
| E | $0.06x(1 + 0.0001x)^{-1/2}$ | $0.03x(1 + 0.0003x)^{-1}$ |
| F | $0.04x(1 + 0.0001x)^{-1/2}$ | $0.016x(1 + 0.0003x)^{-1}$ |
| Urban conditions | | |
| A–B | $0.32x(1 + 0.0004x)^{-1/2}$ | $0.24x(1 + 0.0001x)^{+1/2}$ |
| D | $0.22x(1 + 0.0004x)^{-1/2}$ | $0.20x$ |
| D | $0.16x(1 + 0.0004x)^{-1/2}$ | $0.14x(1 + 0.0003x)^{-1/2}$ |
| E–F | $0.11x(1 + 0.0004x)^{-1/2}$ | $0.08x(1 + 0.0015x)^{-1/2}$ |

Figure 2: Equations for dispersion coefficients for plume dispersion (Crowl D. and Louvar, J., 2002).

The different cases of the Pasquill-Gifford model are listed in the Crowl & Louvar book. The cases depend on whether the release is a plume or puff, in which direction the material is released, and how high the release is from the ground. The higher the release point is from the ground, the longer time it will need to reach the ground and affect people (Crowl D. and Louvar, J., 2002).

However, the Pasquill-Gifford model is not a very accurate method of determining the concentration of released material since a main criteria involved is that the gas is neutrally buoyant. Chlorine is denser than air and is thus considered a dense gas. Therefore, results obtained from the Pasquill-Gifford model should only be taken as estimations. A better model to use would be the Britter and McQuaid model for dense gases. In this model, atmospheric stability classes are not taken into consideration since they have been found to have little or no effect on the results obtained (Crowl D. and Louvar, J., 2002).

## PHAST Simulation Program

Risk assessment software such as PHAST (developed by the Det Norske Veritas Corporation in Oslo, Norway) provides planners and retrofitters with a tool to determine various levels of risk.  According to the DNV North America website (2009), users input data into the tool and it calculates models showing various effect distances based on hazardous event parameters. The software contains more than one thousand and six hundred chemicals and covers the results of leaks, ruptures, and equipment failure; it is used in a variety of industries, including maritime applications, petroleum, and water treatment. Risk assessment professionals can utilize the wide range of options available through this tool to determine worst case and more reasonable risks. . In this software, a model that is called the Unified Dispersion Model (UDM) is implemented in order to produce estimation on the gas dispersion. This model is very complicated and is based on many different dispersion models, such as the Britter and McQuaid and the Pasquill-Gifford models. This model was initially created by developed by Woodward and Cook in early nineties (2002).

A test example for the chlorine plant in Ras-Laffan in Qatar has been considered. What will happen to the surrounding cities of Ras-Laffan, namely Al-Khor and Dhakira, if the pipe connecting the chlorine tank in Ras-Laffan develops a leak form a hole of a 10 mm diameter?

Assumptions: A spherical tank of volume 17.61 $m^3$ containing 24 tons of liquid chlorine at a height of 4 m. The chlorine is stored at room temperature of about 25 degrees C. The tank head is 1 m and the pipe diameter that is used to transport chlorine is 10 cm. This information was received from a few engineers working at Ras-Laffan.

1. Worst- case incident:
    a. Wind speed = 1 m/s
    b. Stability class: G-very stable, with possible fog.
    c. Atmospheric temperature = 45 degrees C
    d. Solar radiation flux = 1.2 $kW/m^2$
    e. Humidity =75 %
    f. Pool temperature (Chlorine T at tank)= 35 degrees C
2. Normal day conditions:
    a. Wind speed = 5 m/s
    b. Stability class: C- sunny/light or no clouds.

   c. Atmospheric temperature = 45 degrees C
   d. Solar radiation flux = 1.2 kW/$m^2$
   e. Humidity =75 %
   f. Pool temperature (Chlorine T at tank)= 35 degrees C

3. Winter day conditions:
   a. Wind speed = 1.5 m/s
   b. Stability class: D.
   c. Atmospheric temperature = 15 degrees C
   d. Solar radiation flux = 0.2 kW/$m^2$
   e. Humidity =70 %
   f. Pool temperature (Chlorine T at tank)= 20 degrees C

The concentration was assumed to be that of 1 ppm and the release rate that of a continuous plume. The entire scenario was based on the Emergency Response Planning Guidelines' concentration models. The distance between Ras-Laffan and Al-Khor and Dhakira cities is about 35 km, and 27 km respectively.

The example used about Ras-Laffan was simulated using PHAST for the three cases involved. The results are recorded as follows: Figure 3 illustrates that there is a leak from a chlorine tank in the form of a continuous plume.

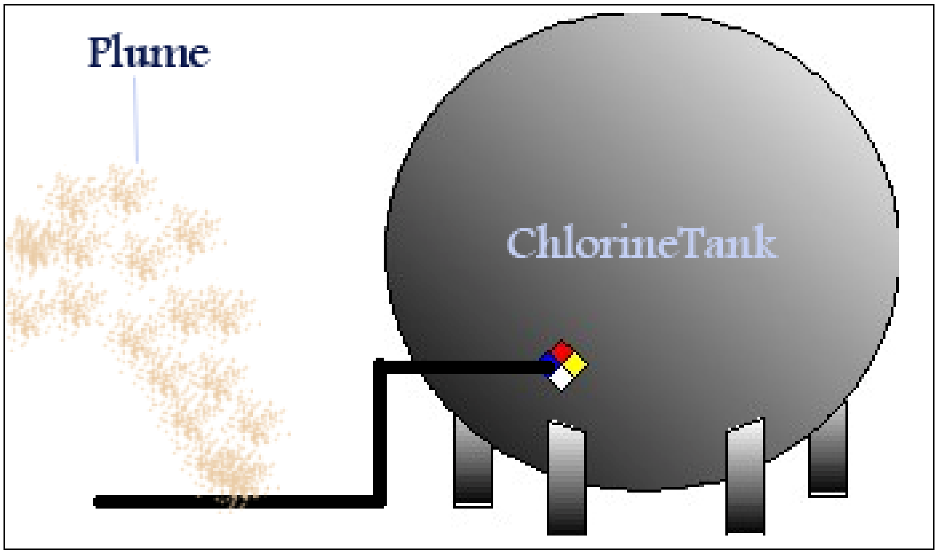


Figure 3: Chlorine tank leak with plume dispersion

Figure 4 shows how far the leak will reach for the worst case scenario with a wind direction of North-West. In this case, it seems that the leak from Ras-Laffan will not reach any of the two surrounding cities.

Figure 4: Dispersion model for the worst case scenario (wind direction North-West)

Figure 5 shows how far the leak will reach for the worst case scenario with a wind direction of North-West as before, but coming in a closer direction from the North. In this case, it also seems that no toxic materials will reach any of the cities, but that if the wind changes more towards the North, there may be a slight possibility of the materials reaching one of the cities.

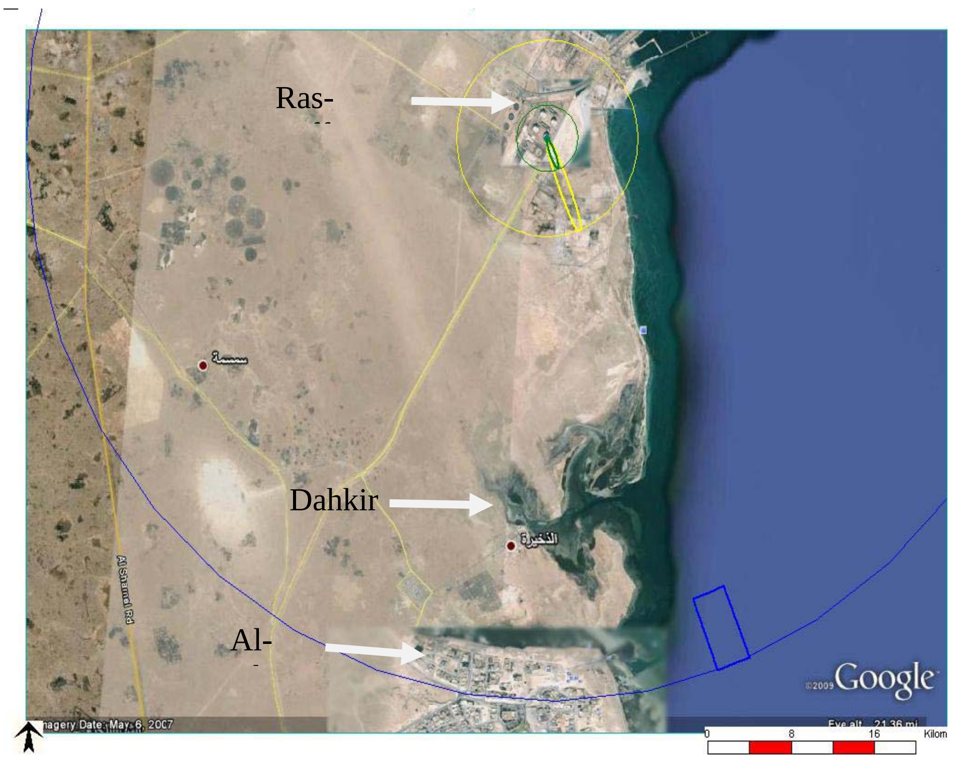
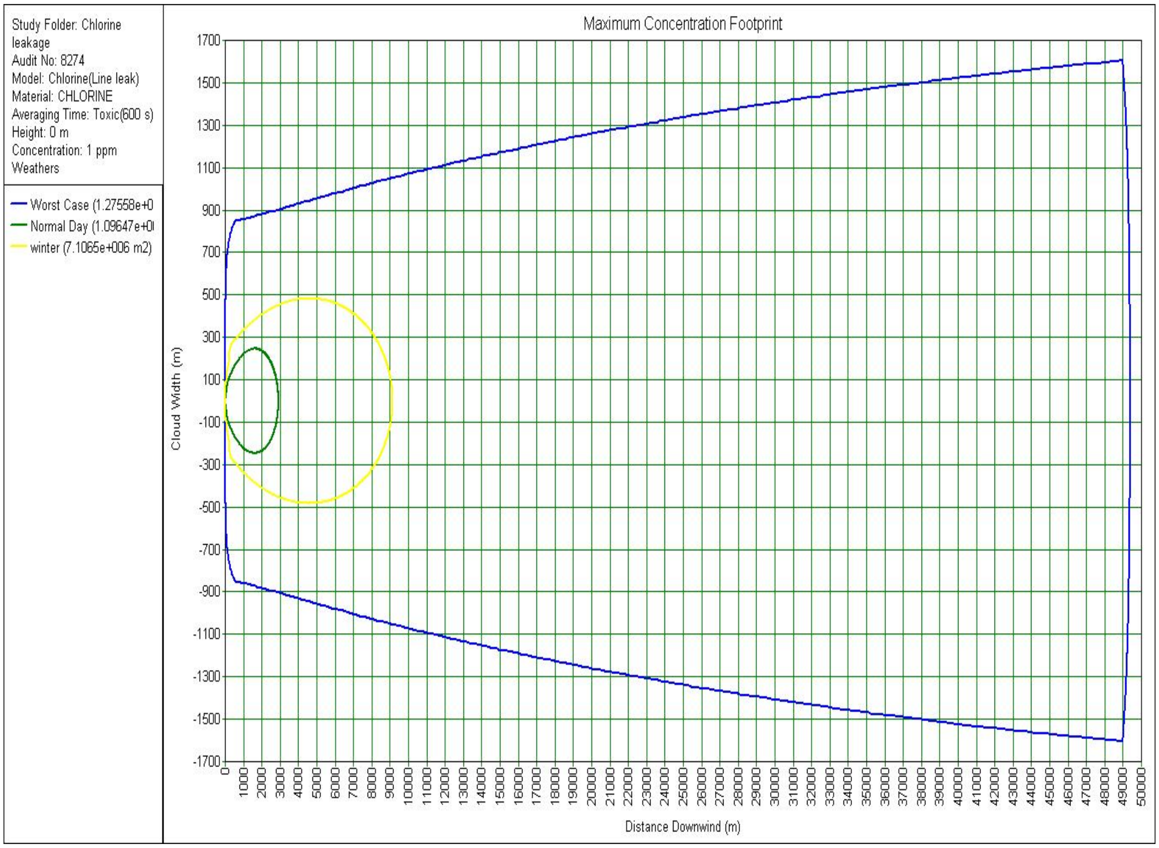


Figure 5: Dispersion model for the worst case scenario (wind direction North-West but more to the North)

The companies at Ras-Laffan assume that the wind direction from that region will always be North-West. If that were true, then the results from PHAST show that there would be no risk of the leak reaching any of the surrounding cities. However, if one day (even though it is extremely unlikely in Qatar) the wind came from the North and there was a leak, one of the surrounding cities may be in danger of exposure to the chlorine leaked. The location of the plant was obviously decided by professional engineers who would have conducted a thorough risk-assessment before deciding on an exact location. The PHAST result that if the wind direction changes then the concentrations may reach one of the surrounding cities should not be taken as a general statement since it is merely a simulation result. It may be that one in a hundred times for example, if the wind direction changes and there is a leak, that the plume concentrations may spread to a nearby city. However, Ras-Laffan professionals should conduct additional assessments to determine what happens when the wind direction changes, in order to protect the residents of nearby cities.

Figure 6 shows the maximum concentration plotted versus distance in one direction for all three cases. The blue line represents the worst-case incident, the yellow line represents normal day conditions and the green line represents winter day conditions.



Study Folder: Chlorine leakage
Audit No: 8274
Model: Chlorine(Line leak)
Material: CHLORINE
Averaging Time: Toxic(600 s)
Height: 0 m
Concentration: 1 ppm
Weathers

Figure 6: Maximum concentration as a function of distance for the three cases

The results from PHAST show that for the worst-case incident, the concentration can spread to a much larger distance than the other two could. This is due to the very low wind speed and weather conditions, which create less turbulence than the other two cases. The more turbulence there is, the more there is mixing of the toxic gas, which reduces the concentration with increasing distance. Consequently, the concentration of toxic gas for normal day conditions travels a greater distance than for winter day conditions. Figure 7 shows how the percentage of fatalities increases as distance increases for each of the three cases.

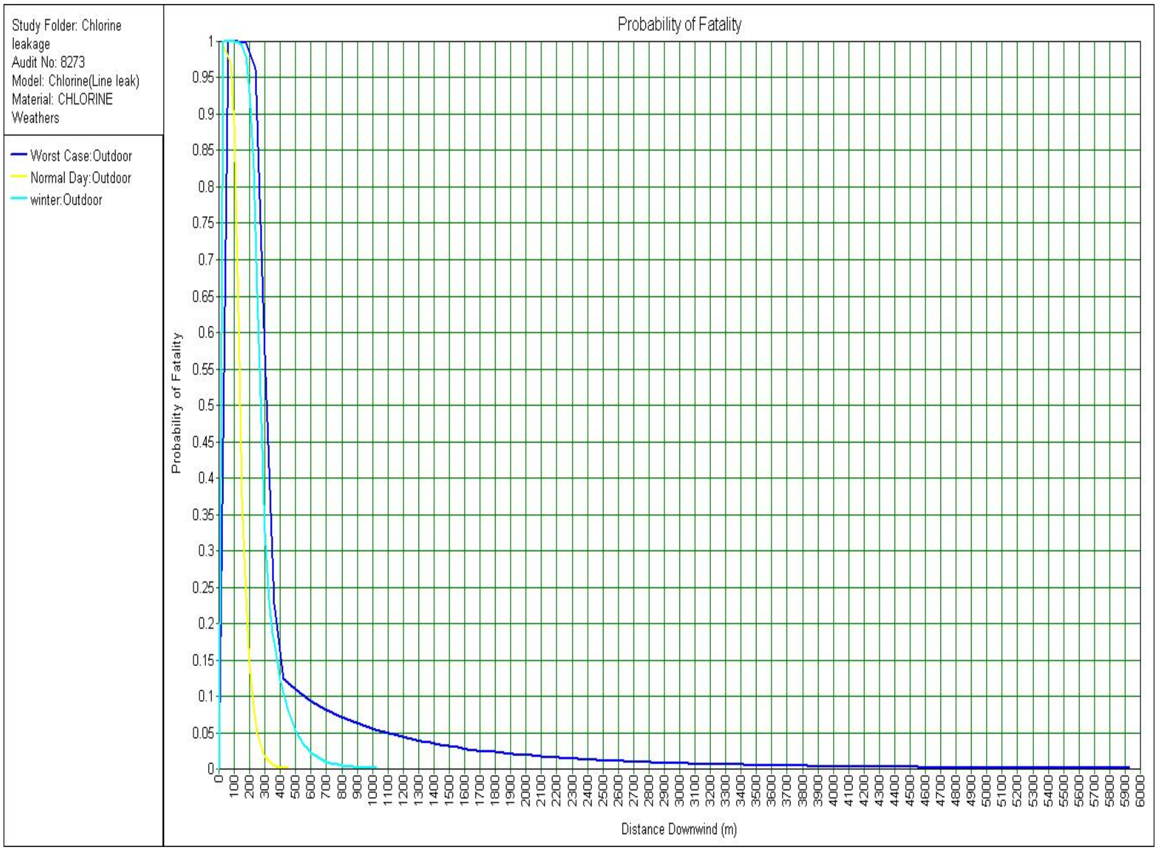


Figure 7: Percent fatalities versus distance

For all three cases, as distance increases, the percentage of fatalities decreases. This is an expected result since as distance increases, plumes concentrations also decrease. Therefore, people would be exposed to lower concentrations, resulting in fewer deaths. Please refer to Appendix 2 for additional figures produced from the PHAST simulation.

One recommendation for the area of Ras-Laffan would be to grow trees in the area between Ras-Laffan and the two cities. This would reduce the toxic effects since air turbulence would increase. Another recommendation would be to increase the number of toxic gas detectors in order to quickly detect the leak so that it can be minimized before it has the chance to reach the surrounding cities. A third recommendation would be to ensure a quick method of alerting the municipalities and government agencies so that they can evacuate the residents of the cities quickly in the case of a leak.

## Real-Life Chlorine Leak Incidents

More than three million tons of chlorine is shipped by rail annually within the U.S. Recently, rail companies have petitioned the Obama administration to refuse to transport toxic chemicals of all types, including chlorine, through population centers (Frank, 2009). The railroad cites “remote but deadly risks” in its petition, and is more motivated by liability protection than the actual risks, which would indeed be deadly if a rail car carrying chlorine gas ruptured (para. 7). The rupture of a one-ton cylinder could potentially produce a cloud one mile high by a half-mile wide by one mile long of toxic mustard gas that will kill everything in its wake. There are indeed catastrophic risks involved with producing, storing and transporting large amounts of chlorine, but fictitious worst-case scenarios created while planning for emergencies do not accurately reflect reality (Logomasini, 2003). As far back as 1987, risk assessors called for more thorough inspections of rail cars to prevent derailments. Technologically advanced steel and double-layered hazardous material protections became used when transporting chlorine gas (Swoveland, 1986). In an incident which sparked the Swoveland article, a train in Ontario derailed and a tank car of chlorine gas ruptured; if there had not been a large propane fire funneling the heavier-than-air mustard gas upwards into the atmosphere, many thousands of people in the city of Mississauga might have died or been injured.

Despite the almost catastrophic outcome of the Ontario incident, real-world accidents are rare and are usually contained within moments of their occurrence. In a 2002 incident in southern California, plant operators had just switched two empty ton containers with two full ones, following all plant protocols. An automatic leak detection system sounded an alarm, the system was automatically closed, and operators also manually closed the system using backup protocols. The valves were closed within three seconds of leak detection, and a horrible event was avoided in less than ten seconds. Approximately one pound of chlorine gas was released into the container room (Connell, 2002). Operators used self-contained breathing apparatus with full chemical suits and emergency leak kits to locate the leak and to fix the problem.

The Agency for Toxic Substances and Diseases has maintained a system of surveillance for substances that are considered hazardous for more than twenty years, but this state-based system is not universal across the U.S. (Hall, Haugh, Price-Green, Dhara, and Kaye, 1996). A single state agency coordinates emergency personnel such as firefighters, first responders, hospitals, and municipal planning agents. A total of three thousand one hundred and twenty five hazardous substance releases were recorded from

1990 to 1992; of these, one hundred and twenty eight involved chlorine as the single substance accidentally released, and approximately thirty percent of those incidents required evacuations of personnel. None of the incidents were considered catastrophic, and none resulted in any deaths due to chlorine gas release.

## Conclusions

Currently, water treatment plants have a variety of means to disinfect water: by using chlorine, heat, ultrasonic waves, iodine, bromine, sodium hydroxide, and ozone. Chlorine is by far the cheapest chemical to use for water treatment, the most widely accepted, and has the fewest risks to public health. It also leaves a “residual” in the water that can accurately be tested to ensure adequate disinfection according to good water treatment practices. Additional technological alternatives to using chlorine and its derivatives are under consideration, such as UV treatments, nanofiltration, and modular ozone generation. At this point, these technologies are novelties and are incredibly expensive to retrofit or to develop from the ground up (Whitfield and Brown, 2009). The Government Accountability Office estimates that converting from chlorine gas to different chemicals would cost wastewater plants between $650,000 and $12 million. The price would change based on the size of the plant, and major municipalities such as Washington and Cincinnati could face price increases until $2 billion (Stephenson, 2007).

This is not to say that process engineers should not explore these options-developing new technologies could reveal a method that works better or be sold at a cheaper price than the current methods. For now, despite its risks, chlorine is a very good choice as a chemical for water treatment.

It seems that the main risk in using chlorine for water treatment does not arise at the plant itself. Leak detection systems, automatic and manual shutoffs, safety protocols, inspections, and so on, contribute to minimizing the risks of a gas leak at a treatment plant. Rail transportation of chlorine gas presents a much bigger worst-case scenario and is an extremely hazard. Extensive research into risk reduction should begin in this area, while water treatment plants should continue to refine their operations as time passes.

## Appendix 1: Pathogenic Diseases Removed Through the Use of Chlorine and Derivatives

Disinfection of public drinking water is vitally important for public safety. The following are some examples of pathogenic diseases transmitted by water (Kerri, 1989, p. 257).

Bacteria

- Salmonella (salmonellosis)
- Shigella (bacillary dysentery)
- Bacillus typhosus (typhoid fever)
- Salmonella paratyhpi (paratyphoid)
- Vibrio cholerae (cholera) (Kerri, 1989, p. 257).

Viruses

- Eterovirus
- Poliovirus
- Coxsackie Virus
- Echo Virus
- Andenovirus
- Renovirus
- Infectious Hepatitis (Kerri, 1989, p. 257).

Intestinal Parasites

- Entamoeba Histolytica (amoebic dysentery
- Giardia Lamblia (giardiasis)
- Ascaris Lumbricoides (Giant Roundworm) (Kerri, 1989, p. 257).

# Appendix 2: Additional PHAST Simulation Figures

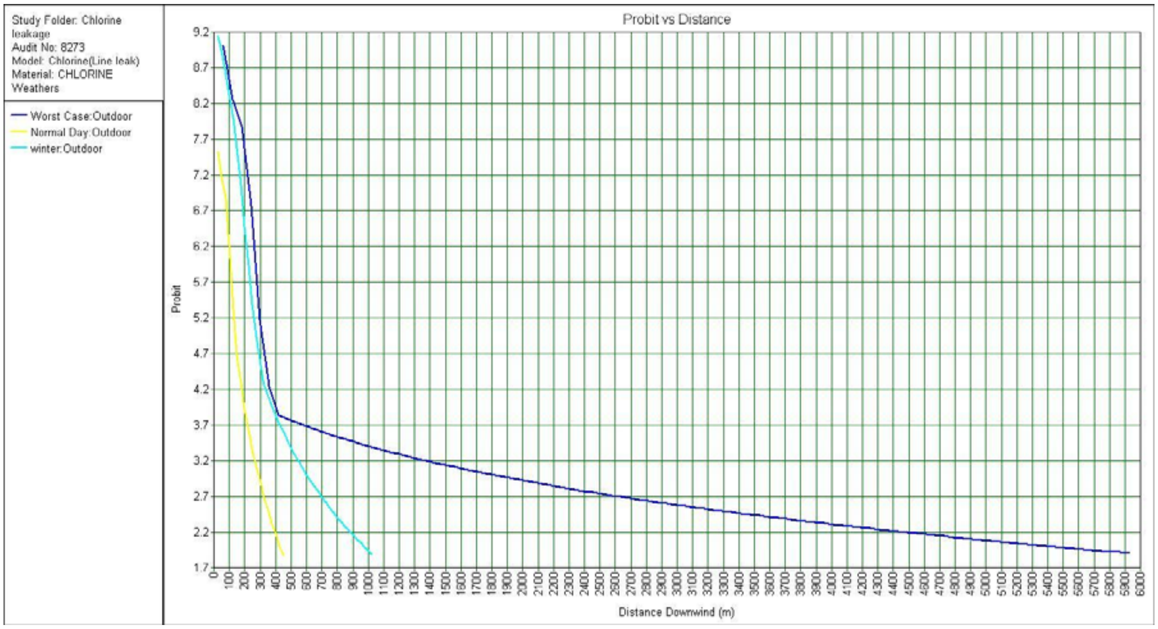


Figure 8: Probit as function of distance

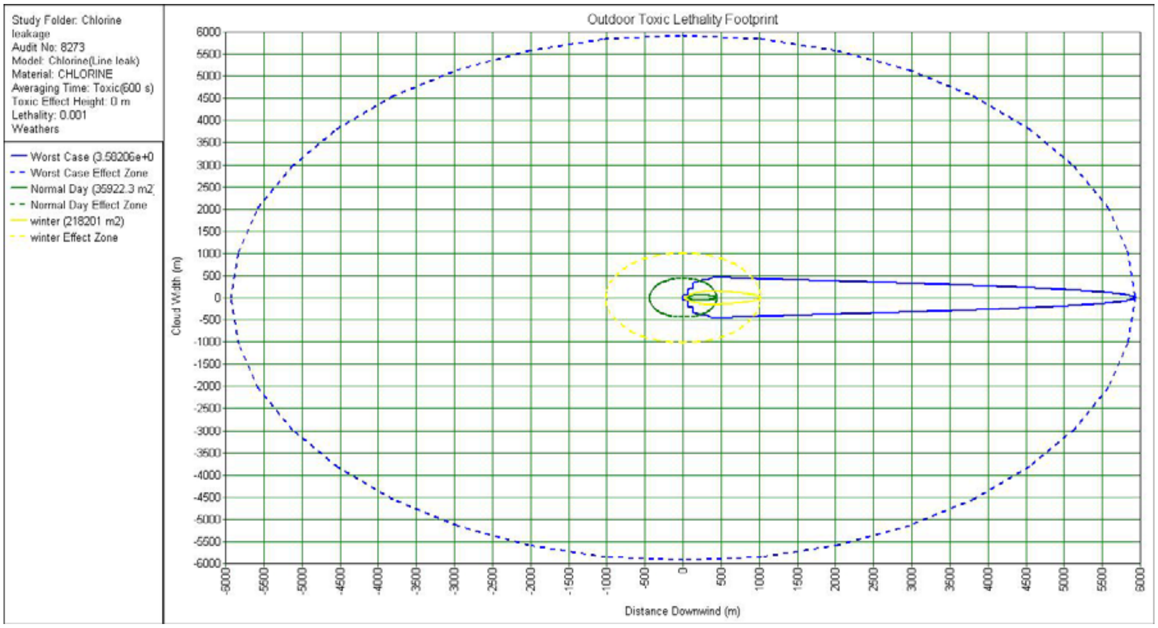


Figure 9: Toxic fatalities versus distance and the zones it can affect

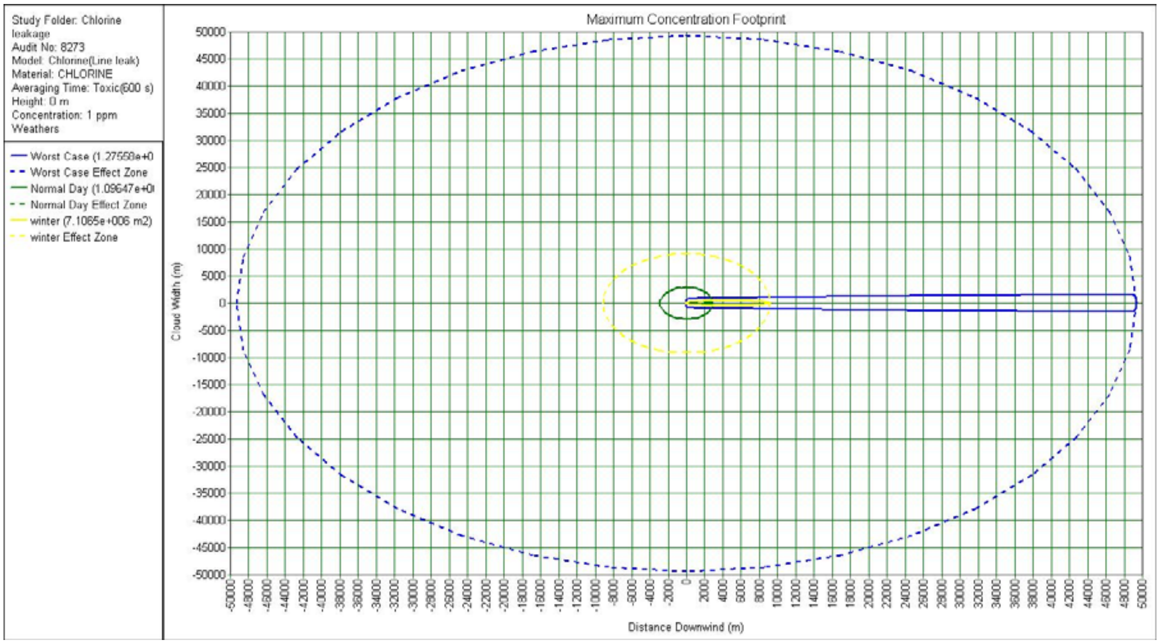


Figure 10: Maximum concentration as a function of distance for the three cases and zones that can be affected with a change in wind direction

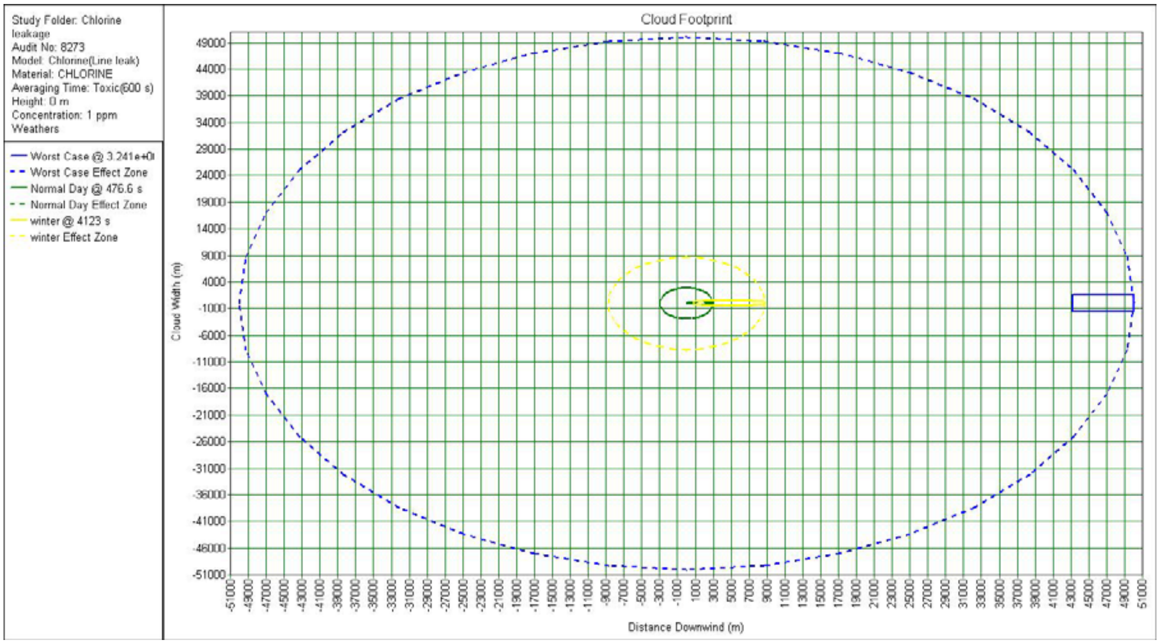


Figure 11: Maximum distance that a toxic cloud can travel in any direction

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