

## NRT Quick Reference Guide: Chlorine Gas (CL)



GHS: Acute Toxicity, Category 1  
 H330 – Fatal if inhaled



GHS: Irritant (skin and eye), Category 2  
 H319 – Causes serious eye irritation  
 H315 – Causes skin irritation



GHS: Oxidizing Gases, Category 1  
 H270 – May cause or intensify fire; oxidizer

### 1. Agent Characteristics

#### Agent Characteristics

**Agent Classification:** Choking/pulmonary, lung damaging agent (CL) and Toxic Industrial Chemical; CAS: 7782-50-5

**Description:** Chlorine (Cl<sub>2</sub>) is a greenish-yellow gas at room temperature with a pungent, irritating odor. Under increased pressure or at temperatures below -30°F (-34°C), Cl<sub>2</sub> is a clear, amber-colored liquid. Cl<sub>2</sub> causes adverse health effects through corrosion and oxidation. Most people can smell Cl<sub>2</sub> at concentrations well below toxic levels, but olfactory fatigue in persons with prolonged Cl<sub>2</sub> exposure greatly decreases this safeguard. Cl<sub>2</sub> can be generated from hypochlorites (e.g., household bleach, disinfectants for swimming pools) at low to neutral pHs. **Cl<sub>2</sub> will react rapidly with atmospheric moisture to form hydrochloric acid (HCl) and hypochlorous acid (HOCl). Cl<sub>2</sub> is a strong oxidizer and may react explosively or form explosive compounds with many common substances, such as acetylene, ether, turpentine, ammonia, fuel gas, hydrogen, fluorine, many other chemicals, and finely divided metals.** Toxic environmental breakdown products of Cl<sub>2</sub> can include HCl, HOCl, and numerous organochlorine compounds. Cl<sub>2</sub> is stored and shipped in pressurized steel containers (e.g., tanks, cylinders, rail tank cars) as a compressed liquefied gas, which is a cryogenic gas that may result in frostbite if released. Pressurized containers may explode when heated. Ruptured cylinders may rocket.

**Persistence:** Cl<sub>2</sub> is considered “non-persistent.” Cl<sub>2</sub> gas: breaks down within minutes to hours through several processes such as photolysis, reactions with moisture or other substances, and dissolution in water; Cl<sub>2</sub> liquid: rapidly volatilizes at ambient temperatures and pressures. Persistence will depend upon the amount and purity of the agent, method of release, environmental conditions, and the types of surfaces and materials impacted. Cl<sub>2</sub> will react with many materials resulting in damage that greatly shortens their usable life (e.g., reduction of metal corrosion resistance).

### 2. Physical and Chemical Properties

#### Physical and Chemical Properties

<b>Molecular Weight:</b> 70.9 g/mol	<b>Formula:</b> Cl <sub>2</sub>
<b>Vapor Density:</b> 2.48 (air = 1)	<b>Flash Point:</b> NA, not combustible
<b>Vapor Pressure:</b> 5,830 mm Hg (77°F/25°C)	<b>Liquid Density:</b> 1.409 g/mL (68°F/20°C)
<b>Volatility:</b> very high, limited by mass transfer	<b>Aqueous Solubility:</b> 7.3 g/L (68°F/20°C)
<b>Boiling Point:</b> -30°F/-34°C	<b>Non-aqueous Solubility:</b> Bases, chlorides, alcohols
<b>Melting/Freezing Point:</b> -150°F/-101°C	<b>Hydrolysis rate:</b> Slow (rapidly reacts with water/moisture)

**Note:** Physical properties are listed at/near STP unless otherwise indicated; NA = not applicable.

**Conversion Factors:** ppm = mg/m<sup>3</sup> x 0.344; mg/m<sup>3</sup> = ppm x 2.90

### 3. Release Scenarios

#### Release Scenarios

**AIR RELEASE SCENARIOS ARE ASSUMED MOST PROBABLE; HOWEVER, OTHER RELEASE SCENARIOS AND EXPOSURE ROUTES SHOULD BE CONSIDERED.**

**Open Areas:** Cl<sub>2</sub> is a gas and is relatively easy to disperse due to its volatility, and the primary release/attack scenario is an airborne release. Cl<sub>2</sub> is expected to disperse or to degrade by reaction with encountered surfaces/materials. However, an unreacted cloud of Cl<sub>2</sub> (typically greenish-yellow) can migrate several miles from the site of release by the wind while maintaining dangerous concentrations in the path of that Cl<sub>2</sub> cloud. Cl<sub>2</sub> in gaseous form is heavier than air, so it can spread along the ground and accumulate in lower terrains and confined spaces (e.g., storm sewers).

**Water/Water Systems:** Cl<sub>2</sub> released into or over natural waters or water systems can dissolve rapidly and form HCl and HOCl, which are corrosive and may exert toxic effects if present in high concentrations. If a large cloud of Cl<sub>2</sub> gas is released, not all Cl<sub>2</sub> may dissolve before the Cl<sub>2</sub> cloud leaves the vicinity of the water.

**Indoor Facility:** Due to its volatility, Cl<sub>2</sub> could potentially be dispersed inside a building or facility; HVAC systems could be impacted. Cl<sub>2</sub> is heavier than air and can accumulate in lower levels, basements, floor drains, or utility corridors inside buildings. Dangerous concentrations may develop quickly in enclosed or poorly ventilated areas inside buildings. Metal machinery and electronics inside a building or facility can be severely corroded.

**Soil/Vegetation:** Soil is unlikely to be contaminated or to act as a sink for Cl<sub>2</sub> deposition. If Cl<sub>2</sub> is released as a gas, it is highly unlikely to contaminate agricultural products. Cl<sub>2</sub> may react with organic matter in agricultural products and oxidize them, mainly leaving nonvolatile chloride-containing compounds or residues, which may cause visual or other damage to vegetation (e.g., necrosis).

**Other:** Cl<sub>2</sub> is not combustible, but it enhances combustion of other substances. Cl<sub>2</sub> is a powerful oxidant, so it can violently react with and/or burn combustibles. Keep combustibles (e.g., wood, paper, oil) away from Cl<sub>2</sub> releases.

## 4. Health Effects

### Health Effects

**4.1. Onset:** Onset of symptoms is dose and route dependent. After exposure, symptoms may occur within seconds after exposure to Cl<sub>2</sub> gas (eyes and respiratory) or Cl<sub>2</sub> liquid (instant frostbite). At higher exposure levels, irritation of the upper respiratory tract and accumulation of fluid in the lungs (pulmonary edema) contribute to a sensation of choking. Suffocation is the characteristic initial complaint after a person is exposed to Cl<sub>2</sub> gas.

**4.2. Signs/Symptoms:** Initial symptoms will vary depending on dose and exposure route. The following is a general list of possible symptoms. The severity of effects depends upon the dosage.

**Mild/Moderate:**

- **Inhalation:** Immediate coughing spasms and a choking sensation; retching and vomiting of stomach contents that may smell like Cl<sub>2</sub>. Hoarseness or complete loss of voice. High-pitched sounds caused by narrowing of the upper airway and severe chest discomfort. An early and prominent effect of exposure is narrowing of the lower airways. The patient or victim may describe the sensation of feeling smothered (suffocated). Symptoms and signs of accumulation of fluid in the lungs (pulmonary edema) may appear within 2-4 hours after exposure.
- **Eye:** Immediate burning, spasmodic blinking or involuntary closing of the eyelids, redness, inflammation of eye's membranes, and tear production.
- **Skin:** Irritation, burning pain, inflammation, and blisters.

**Severe:**

- **Inhalation:** Sudden death can occur from critical narrowing of the upper airway (bronchospasm). Severe difficulty breathing or shortness of breath may be so prominent that the patient or victim refuses to move. Another symptom includes copious secretions (up to 1 liter per hour) from the nose and mouth and airways. Pulmonary edema may occur within 30-60 minutes after exposure. Symptoms may continue for several days after severe exposures.
- **Eye:** Corneal burns leading to cell death and eye ulcers.
- **Skin:** Severe chemical burns leading to cell death and skin ulcers. Exposure to compressed liquefied Cl<sub>2</sub> can result in frostbite injury and/or chemical burns.

**4.3. Exposure Routes:**

**Inhalation:** Inhalation is the main route of Cl<sub>2</sub> gas exposure. Respiratory symptoms may be immediate or delayed for several hours or days after exposure to Cl<sub>2</sub> gas. Respiratory deterioration may continue for several hours.

**Skin:** Contact with Cl<sub>2</sub> in gaseous form can cause chemical burns to skin. Contact with compressed liquified Cl<sub>2</sub> can cause frostbite and/or chemical burns. Significant skin absorption is unlikely.

**Eyes:** Contact with Cl<sub>2</sub> in gaseous form can cause chemical burns to the eyes. Contact with compressed liquified Cl<sub>2</sub> can cause frostbite and/or chemical burns.

**Ingestion:** Cl<sub>2</sub> is a gas at room temperature, making ingestion an unlikely exposure route.

## 5. Effect Levels

### Effect Levels

**5.1. Air: Acute Exposure Guideline Levels (AEGLs)** for general population one-time exposure emergency scenarios for Cl<sub>2</sub> (complete definitions are available at: <https://www.epa.gov/aegl>).

AEGL Level in ppm, at various exposure durations	10 min.	30 min.	1 hr.	4 hr.	8 hr.
AEGL 1: Threshold mild effects	0.5	0.5	0.5	0.5	0.5

<b>AEGL 2:</b> Potentially irreversible effects or impaired ability to escape	2.8	2.8	2.0	1.0	0.71
<b>AEGL 3:</b> Threshold for severe effects/medical needs/increasing potential for lethality	50	28	20	10	7.1

**5.2. Air: American Industrial Hygiene Association (AIHA) Emergency Response Planning Guidelines (ERPG™)** for general population short-term (1 hour) single exposures to airborne concentrations of Cl<sub>2</sub>. (complete definitions are available at: <https://erpg.aiha.org/Content/ERPG.cfm>).

AIHA ERPG Level in ppm	1 hr.
<b>ERPG-1:</b> Mild, transient effects	1
<b>ERPG-2:</b> Serious, irreversible effects	3
<b>ERPG-3:</b> Life-threatening effects	20

**Note:** ERPGs are intended to be used as planning tools for assessing the adequacy of incident prevention and containment measures undertaken for chemical releases. These values are not to be used to determine safe limits for routine operations, as definitive delineators between safe and unsafe exposure conditions, or as a basis for quantitative risk assessment. Additional information can be found at: <https://erpg.aiha.org/Content/About.cfm>.

## 6. Exposure Guidelines

### Exposure Guidelines

**6.1. Occupational:** (NA = not available)

<b>NIOSH IDLH</b> = 10 ppm (29 mg/m <sup>3</sup> )	<b>OSHA PEL</b> = 1 ppm (2.9 mg/m <sup>3</sup> ) [ceiling]
<b>NIOSH REL</b> = 0.5 ppm (1.5 mg/m <sup>3</sup> ) [15-min ceiling]	<b>ACGIH TLV-TWA</b> = 0.1 ppm (0.3 mg/m <sup>3</sup> ) [8-hr TWA]
<b>NIOSH REL-STEL</b> = NA	<b>ACGIH TLV-STEL</b> = 0.4 ppm (1.2 mg/m <sup>3</sup> )

**6.2. Population:**

**EPA Regional Screening Level (RSL):**

RSLs are risk-based concentrations (not exposure guidelines) considered protective for humans (including sensitive groups) over a lifetime. Exceeding an RSL could warrant further investigation, and an appropriate subject matter expert should be consulted. ([www.epa.gov/risk/regional-screening-levels-rsls](http://www.epa.gov/risk/regional-screening-levels-rsls))

**Soil:** RSL for Residential Soil = 0.18 mg/kg; RSL for Industrial Soil = 0.78 mg/kg.

**Drinking Water:** RSL for Tap Water = 0.30 µg/L.

**EPA Provisional Advisory Level (PAL):** PALs represent chemical concentrations in air or drinking water above which varying health effects (PAL1, PAL2, PAL3) are expected. They are developed for 24-hour, 30-day, and 90-day exposure durations. PALs are interim response phase exposure guidelines and are not intended to define cleanup levels.

PAL values are currently unavailable and are undergoing agency review. In the event of a nationally significant or large-scale chemical release, EPA can provide PALs to appropriate end-users and stakeholders as needed to assist in response decision-making.

## 7. Personnel Safety

### Personnel Safety

**Note:** Personal Protective Equipment (PPE) selection (levels A-D), medical surveillance requirements, first aid options, and personnel decontamination may vary depending upon the amount and purity of agent, site conditions, and the release scenario. Additional information on personnel safety and PPE selection criteria can be found at: [www.cdc.gov/niosh/ershdb](http://www.cdc.gov/niosh/ershdb). Responders should also check their own internal procedures (e.g., SOPs), if applicable.

**7.1. Medical:**

**Pre-incident:** Must have current medical and respiratory clearances as part of an Occupational Medical Surveillance Program according to OSHA HAZWOPER and Respiratory Protection Program, as per 29 CFR 1910.

**During Incident:** Conduct periodic on-site medical monitoring, observe for any signs and symptoms as per [Section 4. HEALTH EFFECTS](#) above and treat accordingly as per [Section 7.2. First Aid](#) below.

**Post-incident:** Perform post-incident medical surveillance, as per 29 CFR 1910.

**7.2. First Aid:** Immediately remove person from affected area and remove contaminated clothing and articles.

**Compressed liquid:** Observe and treat for frostbite and chemical burns. Handle frostbitten skin and eyes with caution.

- Place frostbitten skin in warm water. If warm water is not available, wrap the affected part gently in blankets. Let the circulation reestablish itself naturally. Encourage the victim to move the affected part while it is being warmed. Clothing frozen to the skin should be thawed before being removed.
- Flush exposed bare skin and hair immediately with potable water for 3-5 minutes, then wash twice with mild soap or warm, soapy water if available, at normal household pressures (~50-60 psi) for three minutes, ensure thorough soaking. Rinse thoroughly with water.
- Do not irrigate eyes that have sustained frostbite injury. Otherwise, rinse exposed or irritated eyes with potable water or saline for 15 minutes. Eye irrigation may be carried out simultaneously with other basic care and transport. Remove contact lenses if it can be done without additional trauma to the eye. If a corrosive material is suspected or if pain or injury is evident, continue irrigation while transferring the victim to the support zone.

**Gas:** Observe and treat for respiratory distress and maintain clear airway, *effects may be delayed up to 4 hours*. Administer humidified oxygen if respiratory distress develops.

**ANTIDOTE:** There is no antidote for chlorine toxicity.

After administering first aid, send person for follow-up medical attention and evaluation. If cleared to resume work, continue to monitor for signs/symptoms and treat accordingly.

### 7.3. Personal Protective Equipment (PPE):

**WARNING:** Exposure to liquid or rapidly expanding gases may cause severe chemical burns and frostbite to the eyes, lungs, and skin.

**GENERAL INFORMATION:** NIOSH Approved® Chemical, Biological, Radiological, Nuclear (CBRN) Self Contained Breathing Apparatus (SCBA), NIOSH Approved Air Purifying Respirators (APR) or Powered Air Purifying Respirators (PAPR), full-facepieces, and chemical-resistant protective clothing (such as neoprene, polytetrafluoroethylene, and butyl rubber) should be used. Level A protection should be used until monitoring results confirm identity and concentration of contaminant. Pre-incident training and exercises on the proper use of PPE are recommended.

**LEVEL A:** Recommended for the initial response to a Cl<sub>2</sub> incident. NIOSH Approved CBRN full-facepiece SCBA operated in pressure-demand mode with Level A suit that provides protection against CBRN agents. Level A provides the greatest level of skin (totally-encapsulating chemical protective suit and chemical-resistant inner and outer gloves, along with chemical-resistant boots with steel toe and shank), respiratory (SCBA), and eye protection when the contaminant identity or concentration is unknown. Select Level A when the Cl<sub>2</sub> concentration is unknown or above the IDLH or AEGL-2, and when there is a potential of ocular or dermal exposure.

**LEVEL B:** Pressure-demand SCBA (NIOSH Approved CBRN full-facepiece SCBA) with Level B protective suit that provides protection against CBRN agents. Level B provides the highest level of respiratory protection (SCBA) when a lesser level of skin protection is required. Select Level B when the Cl<sub>2</sub> concentration is unknown or above the IDLH or AEGL-2, and when dermal exposure is less of a risk. Level B differs from Level A in that it typically incorporates a non-encapsulating, splash-protective, chemical-resistant outer suit that provides protection against most liquids but is not vapor tight (hooded chemical-resistant outer suit and chemical-resistant inner and outer gloves, along with chemical-resistant boots with steel toe and shank).

**LEVEL C:** May be selected when the contaminant identity and concentration are known and the respiratory protection criteria factors for the use of APR or PAPR (i.e., < IDLH, warning properties) are met. Level C may be appropriate when decontaminating personnel or equipment. Level C still incorporates a hooded chemical-resistant outer suit that provides protection against CBRN agents, chemical-resistant inner and outer gloves, and chemical-resistant boots with steel toe and shank. **Note:** Cl<sub>2</sub> may have limited inhalation warning properties due to olfactory fatigue in persons with a history of prolonged Cl<sub>2</sub> exposure. **Use APR/PAPR with caution and include a canister/cartridge change-out schedule.**

- For air levels greater than AEGL-2: NIOSH Approved CBRN tight-fitting PAPR with a filter or a combination organic vapor, acid gas, and particulate cartridge/filter combination or a continuous flow respirator.
- For air levels greater than AEGL-1: NIOSH Approved CBRN tight-fitting APR with a canister-type gas facepiece or CBRN tight-fitting PAPR.

**LEVEL D:** Select Level D when the contaminant is known and the concentration is below the appropriate occupational exposure limits or less than AEGL-1 for the stated duration times. PPE includes coveralls or other work clothes, boots, and gloves.

**Downgrading PPE levels can be considered only when the identity and concentration of the contaminant and the risks of dermal exposure are known, and must be accompanied by on-site monitoring. Following an assessment of on-site air monitoring data and site hazards by the site safety officer, NIOSH Approved non-CBRN respirators may be considered for use, if appropriate. Cl<sub>2</sub> can react rapidly with water and moisture in the air to form acidic atmospheric conditions that will present a contact hazard to exposed skin as well as inhalation hazards; monitoring for HCl or pH may be required.**

## 8. Personnel Decontamination

### Personnel Decontamination

#### 8.1. Personnel Decontamination Procedure:

Tents, berms, and collection vessels should be able to maintain copious amounts of wastewater in a contained and safe manner. Procedures should be in place to treat and replace contaminated materials used during the decontamination process as well as replace necessary chemicals and decontamination solutions.

Prior to entering the hot zone, all personnel are required to familiarize themselves with the site-specific personnel decontamination procedures.

Personnel decontamination should take place in a decontamination area comprised of two decontamination corridors (one for entering and one for exiting). Position corridors upwind and uphill of release area; exit should be upwind and uphill of entrance. Detergent and water solution (pH>8, but <10.5), soft brushes, and durable 6-mil polyethylene bags should be provided.

Personnel decontamination area workers need to wear appropriate PPE as indicated below. Be aware that absorbed agent can be released from clothing and skin as a gas.

Conduct personnel decontamination per NIOSH ERSB-DB:

[https://www.cdc.gov/niosh/ersbdb/emergencyresponsecard\\_29750024.html](https://www.cdc.gov/niosh/ersbdb/emergencyresponsecard_29750024.html)

- Emergency Responders: Use soft brush to wash PPE with soap and detergent solution in a downward motion, getting into all folds. Repeat washing and rinsing until thoroughly clean. Remove PPE by rolling downward from head; avoid pulling PPE over the head. Remove SCBA last, and place all PPE in polyethylene bags.
- Patient/victim: Remove all clothing down to at least undergarments, and place in polyethylene bags. Thoroughly wash and rinse skin with soap and water solution, taking care not to break the skin and covering all open wounds. Cover patient/victim (e.g., blanket, towels, Tyvek) and move to treatment area.

**8.2. Personnel Decontamination Procedures by Zone/Step:** (attendants will verbally direct personnel through each step)

#### Conducted in Hot Zone (exclusion zone)

1	Equipment Drop	Place equipment taken into the hot zone on a plastic covered table or container provided prior to entering the contamination reduction corridor. Equipment will either be reused if more than one entry is planned or will be decontaminated later.
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#### Conducted in Warm Zone (contamination reduction zone)

2	Sample Drop	Place samples in a container provided for sample decontamination. Care needs to be taken to ensure that workers maintain chain-of-custody of samples. It is recommended that samples are decontaminated in a separate decontamination line.
3	Outer Boot and Glove Wash	The purpose of this step is to enable physical removal of gross contamination if contamination is visible. If gross contamination is not visible, this step may be skipped. Wash outer boots and then outer gloves using designated decontaminating agents (e.g., soap and water).
4	Glove, Boot, and Suit Wash	Wash all outer surfaces in a contained area (e.g., kiddie pool) using a pressurized spray with designated decontamination solution. Start with decontaminating boots and gloves, then work on suit from the top down, including SCBA/PAPR casing. Decontamination personnel should conduct this step. Care should be taken to ensure that all areas are decontaminated, including around zipper, arms, front torso, and any other area that could have come in contact with contamination. The solution used for decontamination should be contained, collected, and disposed of properly from the decontamination line.
5	Outer Glove, Boot, and Suit Removal	While sitting on a stool, remove outer boots and outer gloves. Undo the SCBA/PAPR belt and hold in hand. While touching only the inside of suit, carefully roll suit in an outward motion from shoulders down to feet. Dispose of boots, gloves, and suit in a designated container. This step may require decontamination personnel to assist either by holding SCBA/PAPR unit or assisting in suit removal.
6	Facepiece Removal	With inner gloves, remove the facepiece. Remove cartridge filters and place into designated container. Put facepiece into facepiece wash. Decontamination personnel will clean each facepiece and SCBA/PAPR assembly prior to return to service.
7	Inner Glove Removal	Remove inner gloves by only touching outside of first glove and then only inside of second glove. Place gloves into designated container.

#### Conducted in Cold Zone (support zone)

8	Quadrant Monitoring	Using appropriate Cl <sub>2</sub> air monitoring equipment, screen personnel for residual contamination by dividing body into 4 sections: upper right and left sides of the body, and lower left and right sides. If positive, perform spot decontamination immediately and direct person to showers.
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9	Personal Shower	Personnel should shower using copious quantities of soap and water for a minimum of 5 minutes and change into clean clothes. If a personal shower is not immediately available then, at the minimum, hands and face should be washed thoroughly.
10	Medical Monitoring	Report to medical monitoring station for post-entry monitoring and report to appropriate personnel for debriefing. Observe for any obvious sign of Cl <sub>2</sub> exposure.

**Emergency Egress Corridor:** Establish an emergency egress line to use for quickly decontaminating personnel who have medical emergencies while in the hot zone. Personnel must be decontaminated prior to receiving treatment from emergency medical technicians or transported to a hospital.

**Hand-Wash Station:** A hand-wash station should be available for personnel to clean up following entry. However, this may not be available initially at the scene or weather conditions may prohibit their use. If a hand-wash station is not available, personnel should wash their hands and face as soon as possible.

## 9. Field Detection

### Field Detection

**Real-time field screening tools (non-confirmatory, semi-quantitative): Caution should be given to equipment that has not been properly evaluated. False positive and false negatives may occur in the presence of interferences common in the environment.** The following is a brief representative summary of minimum detection levels (MDL) and ranges for equipment procured by many EPA and HAZMAT response teams. Other screening tools may be used by these teams and other agencies and responders, some with similar capabilities and limitations. Cl<sub>2</sub> as “total chlorine” should be sufficient to monitor in most cases; other forms of chlorine such as “free or residual chlorine” may be appropriate for drinking water or other specific response needs. **CAUTION: Cl<sub>2</sub> reacts with water and moisture in soil and air to form HCl. Monitoring for HCl, which may change the pH of these matrices, and for changes in pH as well as Cl<sub>2</sub> is therefore recommended.** Values are listed as parts-per-million (ppm) and milligram-per-cubic-meter (mg/m<sup>3</sup>) of air or specific concentration units per media.

*Mention of trade names does not convey official approval or endorsement by NRT or any NRT member agency.*

#### 9.1. Minimum Screening Ranges/Levels for Air/(Vapor): 1 ppm = 2.90 mg/m<sup>3</sup>

Field Equipment:	Detection Mode	MDL (ppm)	MDL (mg/m <sup>3</sup> )	Range (ppm)	Range (mg/m <sup>3</sup> )
Dräger – Chlorine detector tubes	colorimetric	0.2*	0.6*	0.2-500**	0.6-1,450**
Dräger – X-am multi-gas or Pac 8000 single-gas detectors (use XXS-Cl <sub>2</sub> sensor)	electrochemical sensor	0.05	0.15	0.05-20	0.15-58
Dräger – X-act with MicroTubes	automated colorimetric	0.05	0.15	0.05-5	0.15-15
Honeywell – SPM Flex	automated colorimetric	0.005	0.015	0.005-5.0	0.015-15
Honeywell – SPM Flex (Mineral acid cassette / HCl)	automated colorimetric	0.02 as HCl	0.06 as HCl	0.02-20 as HCl	0.06-58 as HCl
Honeywell/RAE – MultiRAE multi-gas or ToxiRAE single-gas (Cl <sub>2</sub> sensor)	electrochemical sensor	0.1	0.3	0.1-50	0.3-145
Honeywell BW Solo single-gas (Cl <sub>2</sub> sensor)	electrochemical sensor	0.1	0.3	0.1-50	0.3-145
Blackline G7 (single-gas, multi-gas, EXO)	electrochemical sensor	0.1	0.3	0.1-20	0.3-58

\*: MDL for product with lowest range; \*\*: range across multiple products

Note: For air samples, concentration may be reported as ppm per volume or as mg/m<sup>3</sup>; however, specific meters may report data as one or the other (check manufacturer’s specifications to identify which can be selected).

#### 9.2. Minimum Screening Ranges/Levels for Water:

Field Equipment:	Detection Mode	MDL (ppm, mg/L)	Range (ppm, mg/L)
HACH DR900, Handheld Colorimeter, Free & Total Chlorine (low/high)	colorimetric	0.02 (low) / 0.1 (high)	0.02-2.0 (low) / 0.1-8.0 (high)
Extech EX800 3-in-1 Chlorine, pH, Temp Kit; and Extech CL 200 ExStik Chlorine Meter	ion-selective electrode	0.01	0.01-10
Lamotte Insta-TEST Free and Total Chlorine Test Strips	colorimetric	0.5	0-10
HACH Free & Total Chlorine Test Strips	colorimetric	0.5	0-10
HACH IntelliCAL – ISECL181 Chloride ISE	ion-selective electrode	0.1	0.1-35,000
YSI Xylem – ProDSS chlorine sensor	ion-selective electrode	0.01	0-1,000

Note: The MDL are similar for both free and total chlorine. For waters, ppm and mg/L concentrations are mostly similar; however, specific meters may report data as one or the other (check manufacturer's specifications to identify which can be selected).

## 10. Environmental Sampling and Analysis

### Environmental Sampling and Analysis

**Note:** This section on sampling contains general guidelines and does not replace the need for a site-specific sampling plan.

**10.1. Sampling Concerns:** Detection, sampling equipment and procedures, and analytical techniques will be site-specific and depend on: 1) physical state of the agent; 2) type of surfaces contaminated (e.g., porous vs. non-porous); 3) the purpose of sampling (e.g., characterization, decontamination efficacy, and clearance); and 4) specific laboratory requirements. **Because Cl<sub>2</sub> is reactive and volatile, field detection may be sufficient (and at times necessary) to achieve the goals of sampling, instead of relying on laboratory analysis alone.** The U.S. Environmental Protection Agency (EPA) has set up mobile and fixed labs and analytical assets for chemical agent analysis of environmental samples under their Environmental Response Laboratory Network (ERLN), see [Section 10.5. Analysis](#) below, (<https://www.epa.gov/emergency-response/environmental-response-laboratory-network>). For questions on environmental sampling for Cl<sub>2</sub>, call EPA/HQ-EOC at 202-564-3850.

**10.2. Sample Locations and Planning:** Initially consider air monitoring to ensure worker safety and to determine if there is a Cl<sub>2</sub> cloud that could impact other areas. Characterization sampling is initiated by targeted or judgmental sampling to identify "hot spots," potential agent flow paths, and media or objects potentially acting as sinks. Additional biased or random sampling can be used to determine the extent of potential contamination or to verify the efficacy of decontamination. More thorough probabilistic sampling (e.g., grid, statistical approach) may be required for the clearance phase or if there are large uncertainties about the area impacted or the amount released. Because Cl<sub>2</sub> is generally not persistent, sampling for Cl<sub>2</sub> and HCl (air), and pH (surfaces, water, and soil) to help to "clear areas" should be included in the sampling plan. Because Cl<sub>2</sub> is reactive, significant corrosion may be immediately observable on metals after exposure to high chlorine concentrations (~ >10,000 ppm). This can be a good post-incident indicator of areas impacted by high concentrations of the Cl<sub>2</sub> cloud and inform where additional sampling could take place. [This is only an observation, not a sampling technique.]

**Note:** Cl<sub>2</sub> is highly reactive, especially to moisture, so reaction byproducts, mainly HCl and HOCl, may be detected in the field along with monitoring for changes in pH. These reaction byproducts and changes in pH can be used as markers to determine the extent of contamination of the parent Cl<sub>2</sub>. Laboratory analysis will be necessary for chloramines and other organochlorine reaction byproducts. See [Section 10.5. Analysis](#) below to ensure sampling procedures are compatible with all analytes. Some preparation techniques for both Cl<sub>2</sub> and its breakdown products are available in EPA's Sample Information Collection Documents (<https://www.epa.gov/esam/sample-collection-information-documents-scids>). These provide general information regarding sampling procedures for different media, sampling supplies, sample size, container, holding time, preservation, packaging, and shipping, supporting collection of samples.

#### 10.3. Types of Samples:

**Air (Cl<sub>2</sub> in gaseous form is heavier than air):** On-site Cl<sub>2</sub> monitors may provide sufficiently accurate real-time results. More definite analysis for Cl<sub>2</sub> in ambient air can be determined by using NIOSH Method 6011: Chlorine and Bromine, or OSHA Method ID-101: Chlorine. To assess exposure at breathing level, collect air samples at ~5 feet; to assess off gassing from surfaces and at ground levels, collect air samples at ~6 inches.

**Water:** Dissolved Cl<sub>2</sub> is accurately analyzed in the field using a variety of colorimetric kits using DPD reagents (N,N-diethyl-p-phenylenediamine) or by ion-selective electrode methods. Commercially available kits for measuring chlorine in swimming pool waters can also be used to determine excess chlorine in waters. Delays in transport to lab may result in loss of Cl<sub>2</sub> and inaccurate exposure determination. More definitive analysis for Cl<sub>2</sub> in water can be determined by using EPA Method SW846, Method 9056: Determination of Inorganic Ions by Ion Chromatography, and EPA Method 1912: Potentiometric Determination of Chlorine in Aqueous Samples with Ion-selective Electrode. Measuring the pH of the water may be sufficient as Cl<sub>2</sub> gas dissolved in water will immediately be converted to HCl and HOCl and will have changed the pH. Concurrent air monitoring for Cl<sub>2</sub> is recommended.

**Soil:** For localized "hot spot" areas where soil deposition of Cl<sub>2</sub> reaction byproducts (e.g., organochlorine compounds) may occur, surface soil samples may be analyzed for remaining Cl<sub>2</sub>, pH, and organochlorine reaction byproducts and should be taken from a non-vegetated area to a depth of less than one inch. Measuring changes in the pH of the soils may be sufficient. Sub-surface soil samples (e.g., for organochlorines) may not be necessary unless a large amount of liquid was poured on the ground, or if an underlying aquifer is endangered. Concurrent air monitoring for Cl<sub>2</sub> is recommended.

**Surface Wipes:** Wipe samples are often desired to indicate Cl<sub>2</sub> breakdown products, mainly HCl and assorted chlorinated organics, on non-porous surfaces. Measuring the pH of collected wipes may be sufficient. Concurrent air monitoring for Cl<sub>2</sub> is recommended.

**Bulk:** For hot spot areas where liquid Cl<sub>2</sub> deposition may occur on porous surfaces (e.g., concrete, asphalt), actual pieces (chips) or cores of contaminated surface may be obtained using appropriate tools (scabbling, coring, or drills) for subsequent laboratory extraction analysis for chloramines and other organochlorines. Corrosion damage to some surfaces may be visually obvious. Bulk samples of suspected sink materials may be recommended to rule out absorption of organochlorines into these materials. Concurrent air monitoring for Cl<sub>2</sub> is recommended.

**Other Sample Matrices:** Contact EPA/HQ-EOC at 202-564-3850 for sampling instructions.

**10.4. Sample Packaging and Shipping:** The packaging and shipping of samples are subject to strict regulations established by DOT, CDC, USPS, OSHA, and IATA. For more information, see [Section 12.1. Transportation](#) below. Contact the sample-receiving laboratory to determine if they have additional packaging, shipping, or labeling requirements.

#### 10.5. Analysis:

**CAUTION: Many labs may not be able to perform analysis on all matrices (e.g., wipes and soil).** Reactive compounds such as Cl<sub>2</sub>, HCl, HOCl, and other chlorites/chlorates may be accurately determined in the field using available meters and field kits. EPA's ERLN labs (<https://www.epa.gov/emergency-response/environmental-response-laboratory-network>) will use sample prep and analytical methods from EPA's Environmental Sampling and Analytical Methods (ESAM) (<https://www.epa.gov/esam>). For access to the nearest ERLN laboratory specially trained and equipped for analysis of Cl<sub>2</sub> and its organochlorine reaction byproducts, and methods provided in EPA's ESAM, contact EPA/HQ-EOC at 202-564-3850. The ERLN also maintains EPA's Compendium of Environmental Testing Laboratories (CETL), a database of commercial, federal, state, and academic laboratories, which can be queried for specific analyses and matrices. Analysis on environmental matrices for specific chemical agents can be obtained by querying the database of laboratories listed in EPA's CETL (<https://cfext.epa.gov/cetl/lblogin.cfm?action=None>); prior registration for access to CETL website is necessary.

## 11. Environmental Decontamination/Cleanup

### Environmental Decontamination/Cleanup

**CAUTION: Use water spray only to reduce Cl<sub>2</sub> cloud or to divert Cl<sub>2</sub> cloud drift; do not put water in direct contact with liquid Cl<sub>2</sub>. Avoid allowing water runoff to contact remaining Cl<sub>2</sub> liquid.** Cl<sub>2</sub> is so volatile and reactive that it will either dissipate, be consumed by reaction with surfaces/materials it encounters, and/or be readily neutralized. Large releases, however, may travel long distances before this happens. Hence, most of the environmental decontamination will not necessarily be for Cl<sub>2</sub> itself, but for reaction byproducts, mostly acids and organochlorine compounds. Separate, long-term decontamination strategies will need to be developed if those byproducts are of concern in a particular situation. This decontamination/cleanup section refers to Cl<sub>2</sub> itself.

#### 11.1. Decontamination/Cleanup Planning:

Once site controls are in place, develop a site-specific decontamination/cleanup plan. Environmental decontamination may require a "tiered approach" using a variety of techniques and products. Call EPA/HQ-EOC at 202-564-3850 for more information.

**General Considerations:** A cost vs. benefit evaluation should be undertaken for each decontamination strategy and approach that considers public safety, total cost, impact on the area, wastes generated, time the area or item will be inaccessible and/or out of service, as well as any socio-economic, public health, and/or security impacts that may result. Large volumes of decontamination wastes may be generated that will need to be collected, treated, and disposed of properly. Waste handling and disposal must be addressed as early in the decontamination and cleanup process as possible (see [Section 12. WASTE MANAGEMENT](#) below).

**Disposal Option:** The urgency to restore an area or item as quickly as possible may result in the outright and timely removal and disposal of contaminated materials. Certain materials may be impacted by exposure to Cl<sub>2</sub> itself or from reaction byproducts, and/or may be cheaper to discard and replace than to decontaminate and restore.

**Monitored Natural Attenuation:** Cl<sub>2</sub> degrades via natural processes. Cl<sub>2</sub> oxidizes metals, organics, or other materials it encounters resulting in chloride-containing salts, oxides, and organochlorine compounds. Some of these degradation products may be persistent and/or toxic, which may require additional chemical degradation strategies. Environmental monitoring must be maintained during decontamination and recovery phases. Monitored natural attenuation may require institutional controls (e.g., access restriction and contaminant containment measures). The time to achieve clearance must be considered in the overall cost/benefit evaluation. This option is more passive than other decontamination options and may be more destructive to materials if it allows Cl<sub>2</sub> to react with materials for a longer period of time.

**Fix-in-Place Option:** The contaminated area may be resistant to decontamination products or may be unable or impractical to be treated. Physical barriers can be used to isolate the area until Cl<sub>2</sub> gas has dispersed and to prevent it from coming into contact with the environment or the public. This can be a temporary or permanent solution.

### 11.2. Decontamination Strategy:

A decontamination strategy can be developed by designating contaminated areas based on presence of: 1) liquid chlorine, 2) gaseous chlorine, or 3) aqueous solutions of chlorine. Areas in each category may be treated using one or more unique decontamination processes in a tiered approach to the overall site-specific decontamination strategy.

#### Caution:

- Decontamination products may have unique safety/PPE requirements due to their own toxicity or that of breakdown products during use.
- Cl<sub>2</sub> is a strong oxidizer and may react violently with organics.

**Strategy for Liquid Chlorine:** Presence of liquid Cl<sub>2</sub> in the environment is unlikely. Cl<sub>2</sub> is easier to remove when in gaseous form; actions that promote safe volatilization may be useful. Volatilization may be a slow process depending on environmental conditions.

**Strategy for Gaseous Chlorine:** Aerate spaces where gaseous Cl<sub>2</sub> may be present. Cl<sub>2</sub> has corrosive properties and attacks metals and other materials, including electronics, plastic, rubber, and coatings. Impact on materials should be assessed for mitigation efforts. Mechanical, electrolytic, or chemical cleaning of corroded products may be needed. Forced or Hot Air ventilation methods are recommended for Cl<sub>2</sub> cloud contamination or low concentration of Cl<sub>2</sub> in large volumetric spaces, including HVAC systems. Capture technologies (e.g., activated carbon-containing air filters), if present and/or available, can facilitate the removal of Cl<sub>2</sub> gas from an enclosed area.

**Strategy for Aqueous Solutions of Chlorine:** If Cl<sub>2</sub> is present in solution, contain liquid or transfer liquid to appropriate containers and dispose according to [Section 12. WASTE MANAGEMENT](#) below. Adjusting the pH of acidic solutions to greater than 8.5 with caustic soda, soda ash, or lime solutions will help prevent volatilization of remaining Cl<sub>2</sub> in solution, but some Cl<sub>2</sub> gas may still be evolved even at pH values much greater than 8.5. Neutralizing Cl<sub>2</sub> in solution with thiosulfate, sulfite, ascorbic acid (vitamin C), or other reducing agents converts the Cl<sub>2</sub> to nonvolatile chloride-containing compounds. Avoid any additional release of unreduced solution to water systems, drains, or sewers (e.g., through inappropriate disposal).

**Sensitive Equipment and Items:** For difficult-to-clean equipment thought to be contaminated with small amounts of Cl<sub>2</sub>, additional options for consideration include dissipation via monitored natural attenuation or flushing with water (to remove reaction byproducts).

**Verification of Decontamination:** Site and situation specific. Please contact EPA/HQ-EOC at 202-564-3850 for further assistance.

## 12. Waste Management

### Waste Management

#### 12.1. Transportation:

Federal requirements for the commercial transport of hazardous materials and procedures for exemptions are specified in How to Comply with Federal Hazardous Materials Regulations (HMR), available at:

<https://www.fmcsa.dot.gov/regulations/hazardous-materials/how-comply-federal-hazardous-materials-regulations>.

Chlorine (UN1017) is classified as a Division 2.3 poisonous gas in Hazard Zone B, with subsidiary hazards of Class 5.1 (oxidizer) and Class 8 (corrosive). Chlorine is commonly transported as a compressed liquefied gas. Transport of chlorine (UN1017) is forbidden on passenger and cargo aircraft and passenger rail.

Classification and transportation of waste will depend on its physical form and chemical composition. Waste may meet the definition of one or more hazard classes or be unregulated for transport under the HMR. Waste composed of a mixture of chemicals may be classified in accordance with 49 CFR §172.101(c)(10). If the classification of a hazardous waste is uncertain, it may be assigned a tentative classification in accordance with 49 CFR §172.101(c)(11).

Contact the PHMSA Hazardous Materials Information Center at 1-800-467-4922 or [infocntr@dot.gov](mailto:infocntr@dot.gov) to discuss specific cases.

Additional resources on packaging, labeling, and shipping are available at: <https://www.phmsa.dot.gov/standards-rulemaking/hazmat/hazardous-materials-regulations>.

### 12.2. Waste Management:

Under the Resource Conservation and Recovery Act (RCRA), waste is classified as hazardous waste (subtitle C) or solid waste (subtitle D). It is the responsibility of the waste generator to make a hazardous waste determination (40 CFR §262.11). The RCRA regulations generally define a waste to be hazardous if it is: (1) a listed waste (40 CFR §261.31-§261.32); (2) exhibits specific characteristics (40 CFR §261.21-§261.24); or (3) is a discarded commercial chemical product, off specification species, container residue, or spill residue listed in 40 CFR §261.33. Chlorine-contaminated wastes, including wastes containing reaction byproducts, may exhibit one or more hazardous waste characteristics, such as corrosivity (D002) or reactivity (D003). Listed or characteristic waste may be land disposed only if the waste meets the applicable treatment standards (40 CFR §268.40).

Intact pressurized steel containers (e.g., tanks, cylinders) that may have been compromised or contaminated, but contain Cl<sub>2</sub> as a compressed liquefied gas, could require disposal as well.

The states (except for Alaska and Iowa) have the primary responsibility to implement the RCRA hazardous waste regulations and can impose more stringent requirements or requirements broader in scope than the federal program. It is critical to open a dialogue with state regulators as early as possible to determine any state-specific requirements with regard to chlorine-contaminated wastes. Once identified, potential waste management facilities should also be contacted to determine their waste acceptance criteria.

Management of toxic decomposition products, associated residual decontamination solutions, local waste acceptance criteria, and transportation and handling requirements should be considered. High pH aqueous decontamination solution waste may be considered corrosive hazardous waste, chemical code D002, if it has a pH greater than or equal to 12.5 (40 CFR §261.22).

EPA also recommends the creation of pre-incident waste management plans as a preparedness measure for chemical agent releases, and has created an **All-Hazards Waste Management Planning Tool** to help state, local, territorial, and tribal waste management officials coordinate and prepare these plans. Access to the All-Hazards Waste Management Planning Tool requires pre-registration (<https://wasteplan.epa.gov/>).

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