Rail Car Unloading Case Study

Hazard Identification and Risk Analysis using RAST

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Process Description

Chlorine gas is liquefied by the application of pressure at reduced temperatures to form a clear, amber-colored liquid. Liquid chlorine (a liquefied compressed gas) is more economical to ship and store. Other than at large production facilities, liquid chlorine is typically stored and shipped in 150-pound cylinders, 1-ton containers, or 55- and 90-ton tank cars. One volume of liquid chlorine, when vaporized, yields about 460 volumes of gas.

A chlorine repacking operation involves unloading liquid chlorine rail cars into smaller cylinders and totes. The chlorine repackaging process operation involves the following:

- Connecting a 90-ton (180,000 pounds) chlorine tank car to one of three unloading stations.
- Transferring liquid chlorine from the tank car through the process piping system to filling stations.
- Loading the filled 150-pound cylinders and 1-ton containers onto trucks for distribution.
- Cleaning and preparing empty cylinders and containers for reuse.

The chlorine repackaging process is a one-shift operation, typically running from 6:00 am to 4:00 pm, Monday through Friday. At the end of the day, a packager climbs the ladder to the top of the tank car and closes all car valves manually. Residual chlorine in the piping system is directed to the bleach production process. A vacuum is pulled and the system is left under negative pressure. The chlorine transfer hoses remain connected to the tank car overnight. Leak testing (by spraying small amounts of ammonia solution around possible leak points) is performed prior to startup the next day.

Equipment and Site Description

Railcars are typically 180,000 gallon capacity and rated for 375 psig. They are equipped with 1 inch diameter unloading hoses and automated shut off valves.

The site is located 35 miles south of downtown St. Louis and 3 miles south of both the Festus and Crystal City town centers. Festus and Crystal City have a combined population of 14,000. Nearly 1,500 people live and work within a 1-mile radius of the site. Approximately 200 people live in a mobile home park directly adjacent and southwest of the site (approximately 500 ft from the rail car unloading area). The area beyond the mobile home park (2500 ft away) is sparsely populated. Goodwin Brothers Construction and Intermodal Tire Retreading are located about 100 feet to the east (approximately 500 ft from the rail car
unloading area) separated from the site by Highway 61. Each business has about 18 full-time employees. Interstate 55 is 0.5 miles to the east.

**Inputs for RAST**

Chemical data for the materials used in this example is in the RAST chemical database as provided from CCPS. The RAST chemical data input sheets for chlorine are shown below. An operating pressure of 8 bar has been entered to ensure the physical state is liquid at an ambient temperature of 25 C.

Ensure Physical State remains Liquid (Saturation Temperature < Operating Temperature)
Equipment Data Entry is entered on the Equipment Input worksheet. Note that there are few required fields and information may be added later to improve results. Relief device information has not yet been entered.

Since the rail cars are used for unloading only, the feed rate is entered as zero. If it were possible to back flow from the process into the rail car, a backflow rate would be entered to evaluate an overfill situation.
Plant and Site Layout information is entered on the Plant Layout worksheet. For this example, we have entered two offsite population regions with the mobile home park between 500 and 2500 ft. from the rail car unloading with a population of 200 people across roughly 10 acres (40000 m²) or 0.005 people/m² (densely populated). The area beyond the mobile home park is farmland assumed 0.0001 people/m². The airport is north at more than 5000 ft. away.

<table>
<thead>
<tr>
<th>Location Information</th>
<th>Occupied Building Data</th>
<th>Environmental Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to Property Limit or Fence Line = 500 ft</td>
<td>Distance to Occupied Bldg 1 or Area = 500 ft</td>
<td>Spills to Soil Require Remediation?</td>
</tr>
<tr>
<td>Furthest Distance to Fence Line (&gt; 152.4 m) = m</td>
<td>Elevation of Occ Bldg 1 Ventilation Inlet = m</td>
<td>Potential for Water Contamination?</td>
</tr>
<tr>
<td>Max. Onsite Outdoor Population Density = people/m²</td>
<td>Distance to Center of Occupied Bldg 1 = m</td>
<td>High Population Downstream of Facility?</td>
</tr>
<tr>
<td>Personnel Routinely in Immediate Area?</td>
<td>Occupied Bldg Type =</td>
<td></td>
</tr>
<tr>
<td>Distance to end of Offsite Zone 1 = m</td>
<td>Occupied Bldg 1 Ventilation Rate = changes/hr</td>
<td></td>
</tr>
<tr>
<td>Offsite Population Density within Zone 1 = people/m²</td>
<td>Number of Building Occupants = 18</td>
<td></td>
</tr>
<tr>
<td>Offsite Population Density Beyond Zone 1 = people/m²</td>
<td>Occ Bldg 2 in Same Wind Direction?</td>
<td>No</td>
</tr>
<tr>
<td>Effective Egress from Work Area?</td>
<td>Distance to Occupied Bldg 2 = 2500 ft</td>
<td></td>
</tr>
<tr>
<td>Access for Emergency Services?</td>
<td>Elevation of Occ Bldg 2 Ventilation Inlet = m</td>
<td></td>
</tr>
<tr>
<td>Degree of Equipment Congestion in Area?</td>
<td>Distance to Center of Occ Bldg 2 Type =</td>
<td></td>
</tr>
<tr>
<td>Containment or Dike Surface Area = sq m</td>
<td>Occupied Bldg 2 Type =</td>
<td></td>
</tr>
<tr>
<td>Overstore Dike or Built Facility for Vessel Rupture?</td>
<td>Occ Bldg 2 Ventilation Rate = changes/hr</td>
<td></td>
</tr>
<tr>
<td>Credit Fire Heat Adsorption for Drainage/Indirect?</td>
<td>Number of Occupants Bldg 2 = 18</td>
<td></td>
</tr>
<tr>
<td>Distance to Nearest Fed Equipment = m</td>
<td>Will-Mix Concrete</td>
<td></td>
</tr>
<tr>
<td>Quantity of Other Flammables in Immediate Area = kg</td>
<td>Distance to Nearest Fired Equipment = 500 ft</td>
<td></td>
</tr>
<tr>
<td>Quantity of Flammables in Adjacent Area = kg</td>
<td>Quantity of &quot;Other&quot; Flammables in Adjacent Area = kg</td>
<td></td>
</tr>
<tr>
<td>Adjacent Containment or Dike Surface Area = sq m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automated EBVs to limit spill quantity?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

There is no reaction data input for this example.
Reports

Following entry of the input information, several reports may be run to summarize hazards and risks. A good report to start with is the **Hazard Summary**. Based on the input information, RAST suggests considering toxic hazards. A Process Hazard is also noted due to the low normal boiling point where frostbite may be a concern.
## Summary of Chemical Information

### Physical State at Operating Conditions for Chlorine
- **Weight Fraction Chlorine**: 1
- **Normal Boiling Point, C**: -34.0
- **Flash Point, C**: Note Chemical Information in Bold
- **Lower Flammable Limit at Initial Composition, vol %**: 0.0
- **Combustible Dust?**: No
- **ERPG-2 at Initial Composition, ppm**: 3.0
- **ERPG-3 at Initial Composition, ppm**: 20.0
- **Dermal Toxicity Classification (toxic to Human Tissue)**: No
- **Aquatic Toxicity Classification**: Considered Toxic by a Regulatory Agency? No
- **Heat of Reaction, kJoule/kg**: 0.003785412
- **Highly Volatile or Gaseous Products Generated?**: No
- **Potential for Mixing Incompatible Materials?**: No
- **Considered Condensed Phase Detonable?**: No

## Summary of Equipment and Process Conditions

### Normal Operating Conditions
- **Temperature**: 25
- **Pressure**: 8.00

### Maximum Allowable Working Pressure
- **Catastrophic Failure/Burst Pressure**: 119.4
- **Full Vacuum Rated?**: Not Entered
- **Catastrophic Failure High Temperature**: 600.0
- **Temperature where Low Temp Embrittlement may Occur?**: Not Entered

### Maximum Feed Pressure
- **Maximum from Liquid Displacement (based on x compression or feed pressure)**: 5.82
- **Maximum Feed Pressure**: 25
- **Maximum Gas Pad Pressure**: Not Entered
- **Maximum Downstream Equipment Pressure**: Not Entered

### Estimated Maximum Headspace Deflagration Pressure
- **Maximum Pressure from Hydraulic Surge (Piping Only)**: 25

### Maximum Ambient Conditions
- **Maximum Temperature, C**: 25
- **Minimum Temperature, C**: 25

### Potential for Uncontrolled Reaction
- **Exothermic Reaction Temperature of No Return**: Not Entered
- **Max Reaction based on Adiabatic and Initial Temperature as Operating Temperature**: 25.0

### Potential for Pool Fire
- **Quantity Flammable Available based on Flammable in Area**: 0.0 kg

### Hazard Screening
- **Toxicity Hazard Sufficient for Further Consideration**: Yes
- **Process Equipment is Considered in Hazardous Service**: Yes

### HAZARD SUMMARY

- **Date**: 
- **Toxicity Hazard Sufficient for Further Consideration**: Yes
- **Process Equipment is Considered in Hazardous Service**: Yes

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Another very useful report is the **Scenario List**. Deviations of common Parameters for unloading operations that could lead to an unintended loss of hazardous material or energy along with the most common causes are listed. The list also contains comments why the scenario was selected. Scenarios in gray were not selected. The comments may explain why which may indicate a missing input. This table provides a “starting point” for identifying scenarios to consider for Risk Analysis. Note that “Piping or Equipment Leak” caused by Unloading Hose Failure is one of the scenarios suggested for consideration.

RAST also performs **Consequence Analysis** on each of the scenarios suggested (in addition to any scenarios the User adds). A summary of this analysis is found on the Consequence Summary worksheet. For example, the Incident Type suggested for the Uncontrolled Reaction scenario listed above is Rupture at Saturation Temperature.
RAST Version 1.1
Release Location Outdoors

Airborne Quantity Summary:
- Release Temperature, C: 25.0
- Release Pressure, barg: 8.0
- Physical State at Release Conditions: Liquid
- Heat Input, kcal/min: 2,540
- Equivalent Hole Size, cm: 2.540
- Release Rate, Kg/sec: 5.75
- Release Duration, min: 60.00
- Spray Distance, m: 14.0
- Flash + Aerosol Evaporation Fraction: 0.784
- Estimated Aerosol Droplet Diameter, micron: 99
- Pool Area, sq m: 55.9
- Estimated Pool Temperature, C: -34.4
- Maximum Pool Evaporation Rate, Kg/sec: 1.9973
- Total Airborne Rate, Kg/sec: 6.50
- Total Airborne Quantity, Kg: 19821.4

Airborne Quantity Composition:
- Mole Fraction Chlorine: 1.000
- Mole Fraction Pad Gas (at Mw = 29): 3.2
- ERPG-2 for Vapor Composition, ppm by volume: 21.2
- ERPG-3 for Vapor Composition, ppm by volume: 21.2
- LFL for Vapor Composition, % by volume: 21.2

Dispersion Summary:
- Max Distance to Time-Scaled ERPG-2, m: 3428.0
- Max Distance to Time-Scaled ERPG-3, m: 1237.6
- Max Distance to LFL multiple, m: 2134.8
- Max Distance to 1% Lethality for 1.5 F weather, m: 494.0
- Maximum Ground Elevation Concentration, ppm: 1000000.0
- Concentration at Distance to Fence Line, ppm: 1610.1
- Concentration at Distance to Unrestricted Work Area, ppm: 1610.1
- Concentration at Distance to Occupied Bldg 1, ppm: 64.5
- Concentration at Distance to Occupied Bldg 2, ppm: 64.5
- Concentration within Enclosed Process Area, ppm: 6.50
- Concentration within Enclosed Process Area w/Ventilation, ppm: 6.50

Explosion Summary:
- VCE or Building Explosion Distance to 1 psi Overpressure, m: 64.5
- Overpressure at Distance to Occupied Building, psi: 6.50
- Overpressure at Center of Occupied Building, psi: 6.50
- Distance to Severe Thermal Radiation Impact, m: 1237.6
- Distance to Direct Blast Impact (10 psi), m: 2134.8
- Maximum Fragment Range, m: 2134.8
- Rupture Distance to 1 psi Overpressure, m: 2134.8
- Rupture Overpressure at Distance to Occupied Building, psi: 6.50
- Rupture Overpressure at Center of Occupied Building, psi: 6.50

Consequences:
- Offsite Toxic Impact based on 152.4 m to Fence Line: Yes
- Onsite Toxic Impact with 200 people/km outdoors: Yes
- Onsite Flammable Impact with 200 people/km outdoors: Yes
- Onsite Chemical Exposure with 200 people/km outdoors: Yes
- Onsite Therm Rad Impact with 200 people/km outdoors: Yes
- Occupied Building Toxic Impacts: Yes
- Occupied Building Explosion Impacts: Yes
- Occupied Building Physical Explosion Impacts: Yes
- Environmental Impact: NA

RAST estimated 54 people could be seriously impacted for 3D weather conditions with wind direction directly toward the mobile home park.
The analysis provides tolerable frequency for the various incident outcome based on the company’s risk criteria. In this example, Offsite toxic represents a very high consequence scenario.

Unfortunately, this incident (release of chlorine caused by unloading hose failure) occurred at 9:20 am on August 14, 2002 at the DPC Enterprises repacking facility near Festus, MO. Fortunately, there were no fatalities but 66 people sought medical help. The hose failure was due to installation of an improper stainless steel rather than the required Hasteloy C hose.

CSB Final Report – CHLORINE RELEASE, DPC Enterprises. Figure 14 - Chlorine release at tank car station #3

CSB estimated that a concentration of 3 ppm could have extended as far as 3.7 mile on the morning of the release where the wind speed was in the range of 1.5 to 2.5 m/sec. RAST estimated a distance of 2.1 miles to 3 ppm at a wind speed of 3 m/sec and 3.0 miles at a wind speed of 1.5 m/sec with Class D atmospheric stability (which is in good agreement). Fortunately, wind was in the opposite direction of the mobile home part toward the Intermodal Tire facility where employees were able to successfully evacuate.

Finally, RAST provides a list of possible cause-consequence scenario cases that may be selected as a starting point for Layers of Protection Analysis (LOPA). In addition to the scenario that occurred at DPC Enterprises, RAST provided an additional 23 cause-consequence pair cases. These cases (in addition to cases the study team identifies) may be evaluated by LOPA to ensure compliance with a company’s risk criteria. RAST allows a Technical Administrator to enter a company risk matrix or table of tolerable frequencies for severe consequences. In this example, a tolerable frequency of $10^{-7}$ / year was entered into RAST for a scenario with the potential to result in multiple offsite fatalities.

RAST contains Initiating Event frequencies and Probability of Failure upon Demand factors for common causes and protective layers used in LOPA analysis. RAST provides a LOPA format that helps to document process risk and the protective layers needed. A description of the scenario and tolerable frequency with key information from the Consequence Analysis is provided.
Information regarding Protective Layers such as instrumented interlocks, pressure relief systems, and other safety related protection systems may be captured by the analysis team in addition to the safety integrity level or probability of failure on demand. Once the mitigated scenario frequency meets the tolerable frequency, the scenario is considered adequately managed.

Reference: