Emergency Planning Zones (EPZ) Around Potential Major Technological Accident Sites

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Abstract

This article presents a methodology to establish the emergency planning zones around a site that presents risks of major technological accidents involving hazardous substances. A process to reduce the impact zones from these accidents is also presented. A concrete example involving an ammonia refrigeration system is included to illustrate the subject. The identification of the emergency planning zones is critical for public safety and is used for the preparation of emergency response plans by the site and the public emergency response organizations.

Keywords: Hazardous substances, emergency response plans, accident scenarios, consequence modeling.

Introduction

Preparing for major chemical process emergencies in the vicinity of an industrial site is not an easy task. Hazardous substances exhibit multiple characteristics that emergency responders must be aware of prior to responding to an incident. Environment and Climate Change Canada's (ECCC) environmental emergencies regulation (E2) requires that establishments elaborate an environmental emergency plan (EEP) when the quantity and concentration of one or several of the chemicals listed in the regulation exceeds the thresholds therein. This article summarizes a process that has been successfully used to identify the emergency planning zones (EPZ) that constitutes an essential part of the EEP. Emergency responders should ensure that such establishments in their jurisdiction have followed such a process to properly prepare in case of emergencies. Additionally, joint emergency planning committees can be successfully used to share relevant information, prepare community emergency response plans and organize effective communications to those potentially affected by an accident, as required by the ECCC laws and regulations (Gouvernement du Canada, 2022). This requirement and guidance on EPZ can also be found in the oil and gas CSA standard Z246.2 (*Emergency preparedness and response for petroleum and natural gas industry systems*).

Understanding the chemical properties

Hazardous substances are numerous and the consequences resulting from an accident can differ greatly between substances. Typically, substances are classified as toxic to life, flammable and reactive. Each substance safety data sheet (SDS) must be carefully reviewed to ensure that its properties are understood.

Toxicity

There are different ways to document the level of toxicity of a substance. Workplace exposure limits (for chronic exposure of the workers) for common substances are well documented (TWA, STEL, IDLH, etc.). In the case of an accidental release (acute exposure of people), acute exposure protective action criteria (PAC) for the general population are normally reported as AEGL-1 (mild, transient health effects), AEGL-2 (irreversible or other serious health effects that could impair the ability to take protective action) and AEGL-3 limits (life-threatening health effects) (U.S. Department of Energy, n.d.). As an example, for anhydrous ammonia, the following values exist (Bibliothèque et Archives Canada, 2011):

TWA (*time weighted average – 8 hour-day/40 hour-week*): 25 ppm

STEL (*shorth term exposure limit – 15 minutes*): 35 ppm

IDLH (*immediately dangerous to life or health*): 300 ppm

AEGL (*acute exposure guidelines*)-1: 30 ppm (60 minutes) – other values exist for shorter or longer exposure time for all 3 AEGL)

AEGL-2: 160 ppm

AEGL-3: 1 100 ppm (60 minutes)

EEP's will normally be based on AEGL's values for off-site impacts on nearby populations (see reference 2). There are however other values that can be used in the absence of AEGL values for a given substance, such as ERPG.

Note: Toxicity for the environment (wildlife and flora) is not taken into account in this article.

Flammability

A substance flammability is normally characterized by its flash point (for flammable liquids) and its flammability limits as volume percent in air (for vapors and gases). Lower and upper flammability limit (LFL and UFL) can be found in the literature. Outside those limits, a vapor/air mixture is either too lean or too rich to burn or explode. Loss of containment of a flammable substance can results in a vapor dispersion without ignition or in a flash fire, a pool fire or a jet fire if ignited. Under specific circumstances, an explosion could occur (depending on the level of confinement/congestion of the vapor cloud and the substance reactivity).

Note that a substance can be both toxic and flammable. This, for example, is the case for ammonia, which has AEGL values as well as a LFL of 16% and an UFL of 25%.

Reactive chemicals

Some substances are unstable and can decompose when exposed to heat or react violently if mixed with incompatible substances like water, oxidants, acids or bases. It is beyond the scope of this article to discuss these particular cases. SDS's provide the necessary information to properly assess their behavior.

Identifying the emergency planning scenarios

It is crucial that emergency planning scenarios be determined using a rigorous risk analysis process and not solely based on experience. Several standards (among them CSA Z767-17, CSA Z246.2 and ISO 31000-18) and methods (for example What-if and HAZOP methodologies) exist to that effect. The risk analysis process normally includes the following steps:

1. Assembling a multidisciplinary team;
2. Collecting the information on the process under study (P&ID's, layout drawings, operating procedures, etc.);
3. Establishing risk evaluation criteria;
4. Identifying hazards (following the selected method);
5. Identifying potential events (accident scenarios);
6. Analyzing and evaluating the risk levels for each event;
7. Proposing risk reduction measures to reduce the risk to an acceptable level, as required;
8. Evaluating the residual risk;
9. Implementing any new risk reduction measures identified during the analysis;
10. Selecting the emergency planning scenarios to be included in the EEP.

To perform step 10, the emergency planning scenarios should be those having the highest level of residual risk (meaning the highest combination of severity and likelihood). For similar risk levels between two or more scenarios, those having the highest severity (e.g., largest impact distance) should be selected.

In some specific cases, dispersion, fire and explosion modelling could be useful to get a more thorough evaluation on the severity of each scenario.

Note: Well documented emergency planning scenarios can be found for generic (common) processes (Rébublique Française, 2014). Propane storage is a good example of such a process. Site personnel should ensure that the said scenarios properly cover their installation prior to using them.

Establishing emergency planning zones (EPZ)

Once the emergency planning scenarios have been identified, their consequences must be estimated using dispersion and/or fire and explosion models/tools. One must remember to use extreme caution when interpreting the modeling results. They should be considered as orders of magnitude because:

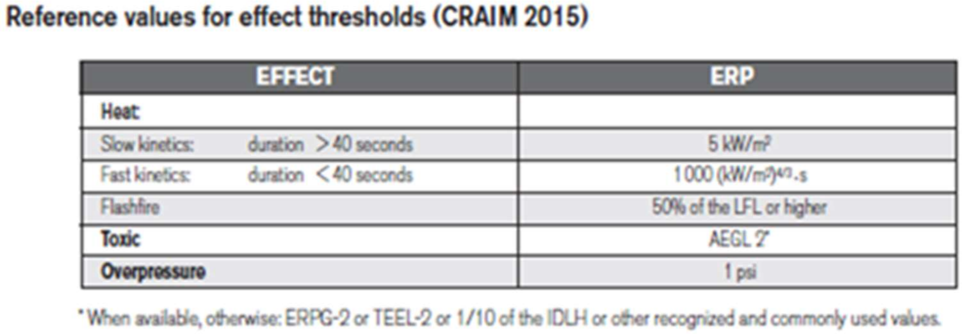
- Existing modeling software can be imprecise and most certainly makes assumptions and approximations that may not accurately represent all the site characteristics (for example site topography, the presence of nearby buildings and obstacles, etc.);
- Accidents rarely occur exactly as predicted by the risk analysis. For example, process and weather conditions during an actual incident may be considerably different from those used in the modeling process.

The simulation of the consequences of an accident scenario comprises three separate but related steps:

1. Source term calculation: this consist in calculating the amount (and/or rate of release) of the hazardous substance that is leaking into the environment. This is essentially a straightforward fluid mechanics calculation that depends on the breach size and location, process operating parameters and the physical and thermodynamic properties of the substance involved.
2. Dispersion modeling: this consists in estimating the size and behavior of the vapor cloud and/or liquid pool that result from the release according to various meteorological and topography conditions.
3. Consequences evaluation: depending on the substance properties (toxicity or flammability), the impact zones must be assessed. All potentially dangerous outcomes from the release scenario are evaluated, such as:
    a. Toxic effects on site employees and off-site neighbors.
    b. Thermal radiation from pool, jet and flash fires,
    c. Overpressure (shockwave propagation) from an explosion, etc.

It is beyond the scope of this article to discuss in detail the measurement units and associated threshold values to be used for emergency planning. Table 1 lists commonly used values (Conseil pour la Réduction des Accidents Industriels Majeurs (CRAIM), 2017).

Table 1- Threshold values for emergency response plans (ERP)



Reference values for effect thresholds (CRAIM 2015)

EFFECT		ERP
Heat		
Slow kinetics:	duration >40 seconds	5 kW/m²
Fast kinetics:	duration <40 seconds	1 000 (kW/m²)$^{4/3}$.s
Flashfire		50% of the LFL or higher
Toxic		AEGL 2*
Overpressure		1 psi

* When available, otherwise: ERPG-2 or TEEL-2 or 1/10 of the IDLH or other recognized and commonly used values.

Several modeling software can be used to facilitate the above-mentioned calculations. Some are free (RMP Comp©, ALOHA©) but present significant limitations while others are expensive but are more comprehensive (accuracy and range of applications) and flexible (PHAST©, FLACS©, etc.). Software selection is critical for public safety and the simulations must be performed by a qualified professional to ensure that model input parameters and results are valid and can be used to prepare the EEP.

Once the emergency planning zones have been assessed, they should be used to:

1. Identify the land usages within the zones, especially sensitive occupations like hospitals, schools, etc. since this might require additional resources to ensure their safety in case of an incident.
2. Prepare communication plans to the community potentially affected by an accident.
3. Install sirens and/or other communication tools (public alert systems) to be used to alert the population in case of an emergency.
4. Prepare specific emergency response procedures.
5. Coordinate response plans with the public emergency services.
6. Determine if additional risk reduction measures are needed.

Reducing the consequences of an accident

Once the risk analysis has been performed, the EEP scenarios identified and their impact zones evaluated, it is common for a site to want to reduce the size of the emergency planning zones and to minimize the effect on the nearby population thus facilitating the emergency response. Risk reduction measures can be identified and recommended to site management. It is common to use the hierarchy of controls to ensure that the risk reduction measures are sufficiently robust and reliable to properly prevent accidents and/or manage their consequences. The hierarchy of controls, by order of efficiency, are as follows (CRAIM, 2017):

1. Inherent safety: eliminate or reduce the hazard at the source through substitution, reduction, simplification, and lower intensity. For example, using concentrated liquid bleach instead of gaseous chlorine in water treatment systems.
2. Passive measures: those that require no energy or equipment to function like tank dikes, firewalls, etc.
3. Active measures: control systems and interlocks, like fire sprinkler systems that require sensing equipment, activation devices, etc.
4. Alert systems: fire alarms for example.
5. Administrative measures: operating and maintenance procedures, emergency plans, etc.
6. Personal protective equipment: Self contained breathing air systems, cartridge masks, etc.

The number and efficiency (reliability) of risk reduction measures must be attuned to the risk evaluated for each accident scenario, i.e., the higher the risk the more robust and diverse the risk reduction measures that are required. Using multiple risk reduction controls simultaneously for a given situation typically has a cumulative effect, thus reducing the probability of incident occurring or reducing its impact should it occur.

Practical example: Ammonia refrigeration

Process description

The following figure (République Française, 2015) depicts a typical ammonia refrigeration system. A mechanical room houses a compressor system, a high-pressure liquid storage tank and a lower pressure/temperature liquid storage tank where liquid ammonia is stored. A pumping system feeds low temperature liquid ammonia to various evaporators located outside the mechanical room through a piping system often located outside the mechanical room and/or outside on the roof of the building. Low pressure cold ammonia vapors (having absorbed heat through liquid ammonia evaporation) are routed back to the compressor system. Higher pressure ammonia vapors are then condensed in an evaporative condenser typically located outside, on the roof of the mechanical room. Warm liquid ammonia coming from the condenser is routed by gravity to the high-pressure storage tank and then to the low-pressure ammonia tank through a level control valve. The cycle then repeats itself.

The compressors are often lubricated through direct oil injection. This oil is recovered in the system through a separation and drainage system and reused. An emergency ventilation system is normally present in the mechanical room and is automatically activated upon detection of a high ammonia concentration inside the room.

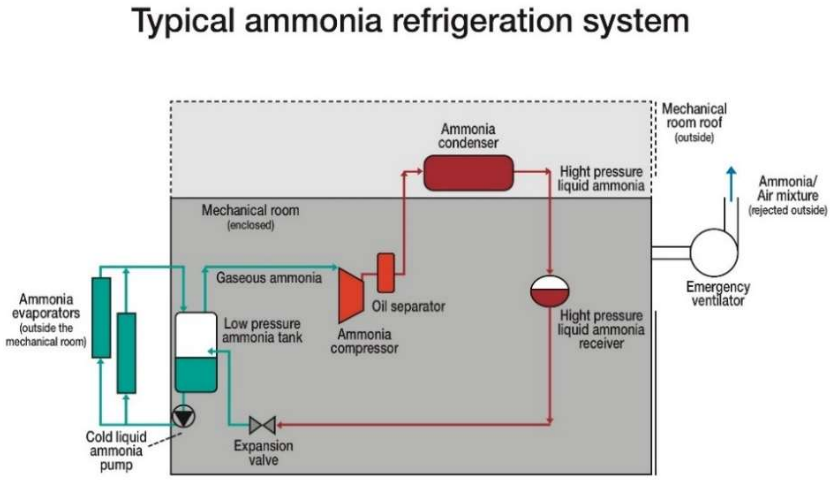


Figure 1- Typical ammonia refrigeration system flow diagram

Emergency planning scenarios identified

Three accident scenarios, that may present significant off-site consequences, are typically associated with the above-mentioned ammonia system (République Française, 2015):

1. Liquid or vapor ammonia leak inside the mechanical room. Ammonia vapors are evacuated outside the mechanical room through the emergency ventilation system.
2. Liquid ammonia leak at the outlet of the condenser on the mechanical room roof. Liquid ammonia is released directly outside, evaporates, and is dispersed in the environment.
3. Liquid ammonia leak between the liquid ammonia pump and the evaporators located outside the mechanical room. Cold liquid ammonia is released outside and pools on the building roof, evaporates and is dispersed in the environment (a similar leak inside the building would have less off-site consequences because it is confined by the building's envelop).

These three accident scenarios may present a risk to neighbors and should be evaluated for inclusion in the site EEP.

Consequence modeling results

Consequence modeling for the above-mentioned scenarios should be tailored to the actual site under study. For the benefit of the reader, an example adapted from an actual site data is supplied below

1. Leak inside the mechanical room: The following table shows the impact distance to the AEGL limits (for 60 minutes, using the PHAST software) based on the rupture of a ¾ inch connection on the high-pressure receiver vessel. The results are presented under two standard atmospheric conditions that represent typical night and day situations.

Table 2 –Simulation results for the ¾ inch connection break inside the mechanical room – horizontal evacuation

Leak inside the mechanical room through a broken ¾ inch connection on the high-pressure receiver. Vapors are released to atmosphere outside the building through the emergency ventilation system (horizontal evacuation). The release is interrupted by the high concentration interlock inside the mechanical room.		Maximum inventory: 585 kg Operating pressure: 180 psig Mechanical room volume: 35000 cubic feet Ventilation flow rate: 14 500 cfm Height of the ventilation outlet: 37 feet Outside temperature: 25°C Release duration in the room: 60 s		
		Distance to toxic endpoints		
		AEGL 1 - 30 ppm (60 minutes)	*AEGL 2 – 160 ppm (60 minutes)*	*AEGL 3 - 1100 ppm (60 minutes)*
Wind speed (stability) - 1,5m/s (F) (typical night conditions)	Maximum distance at 1m from ground level	4100 m	**2000 m**	800 m
Wind speed (stability) - 3,5m/s (D) (typical day time conditions)		2550 m	1200 m	300 m

Note: Calculation results show that the ammonia concentration in the mechanical room would reach the 16% LFL limit after 30 seconds, thus presenting a risk of explosion.

2. Leak at a broken ¾ inch connection at the condenser outlet on the roof. The following table shows the impact distance to the AEGL limits (for 60 minutes, using the PHAST software);

Table 3 – Simulation results for the condenser outlet ¾ inch connection break, no interlocks

<table>
<tr><td colspan="2">Break of a ¾ connection at the condenser outlet on the mechanical room roof. An ammonia pool is forming, ammonia evaporates and is dispersing into the ambient air. The system total inventory is released (no existing mechanism exists to detect and stop the leak).</td><td colspan="3">Maximum inventory: 6400 kg
Operating pressure: 180 psig
Process temperature: 34,9 °C
Direction of release: Horizontal
Release elevation from the ground: 37 feet
Ambiant temperature: 25°C
Leak and evaporation duration: 860 s</td></tr>
<tr><td colspan="2" rowspan="2"></td><td colspan="3">Distance to toxic endpoints</td></tr>
<tr><td><i>AEGL 1 - 30 ppm (60 minutes)</i></td><td><i>AEGL 2 - 160 ppm (60 minutes)</i></td><td><i>AEGL 3 - 1100 ppm (60 minutes)</i></td></tr>
<tr><td>Wind speed (stability) - 1,5m/s (F)</td><td rowspan="2">Maximum distance at 1m from ground level</td><td>8775 m</td><td>4100 m</td><td>1200 m</td></tr>
<tr><td>Wind speed (stability) - 3,5m/s (D)</td><td>3600 m</td><td>1200 m</td><td>200 m</td></tr>
</table>

3. Leak at a broken ¾ inch connection on the low temperature ammonia pump discharge piping on the building roof. The following table shows the impact distance to the AEGL limits (for 60 minutes, using the PHAST software).

Table 4 – Simulation results for the ¾ inch connection break on the cold ammonia supply line, no interlocks

<table>
<tr><td colspan="2">Leak from a broken ¾ inch connection on the building roof downstream the cold ammonia pump. The system total inventory is released (no existing mechanism exists to detect and stop the leak).</td><td colspan="3">Maximum inventory: 6350 kg
Normal operating pressure: 25 psig
Liquid ammonia temperature: -11.5 °C
Pump nominal flow rate: 98 gpm
Direction of the release: Horizontal
Height of the release: 37 feet
Ambiant temperature: 25°C
Leak and evaporation duration: 1524 s</td></tr>
<tr><td colspan="2" rowspan="2"></td><td colspan="3">Distance to toxic endpoints</td></tr>
<tr><td><i>AEGL 1 - 30 ppm (60 minutes)</i></td><td><i>AEGL 2 - 160 ppm (60 minutes)</i></td><td><i>AEGL 3 - 1100 ppm (60 minutes)</i></td></tr>
<tr><td>Wind speed (stability) - 1,5m/s (F)</td><td rowspan="2">Maximum distance at 1m from ground level</td><td>8250 m</td><td>3600 m</td><td>580 m</td></tr>
<tr><td>Wind speed (stability) - 3,5m/s (D)</td><td>2400 m</td><td>725 m</td><td>100 m</td></tr>
</table>

The modeling results show that the impact distances are most likely to have off-site consequences that would be dangerous to the people present within these zones. These scenarios should therefore be used to prepare the site EEP. The emergency planning scenario, i.e., the one having the largest impact distance, is the ammonia leak at the outlet of the condenser on the building roof and should therefore be used as the basis for the response planning. By considering the largest distance, we also cover scenarios that present the same effect with smaller distances.

Potential risk reduction measures

Several risk reduction measures can be implemented to reduce the impact distances of the three scenarios mentioned above. Each site must assess the land uses in the vicinity, the number of persons present, the presence of sensitive uses such as hospitals, long term care facilities, schools, etc. to determine if additional risk reduction measures are required. Examples of such measures are:

1. Replace ammonia with a less dangerous refrigerant.
2. Reduce the overall ammonia inventory in the system.
3. Limit the presence of ammonia to the mechanical room through the use of heat transfer fluids and/or equipment relocations.
4. Install a scrubber to remove ammonia from the air released from the mechanical room emergency ventilation system.
5. Modify the emergency ventilation system to facilitate the dispersion of the ammonia released (use of strobic or high plume dilution fans, increase the upward speed of the released air/ammonia mixture, etc.) and ensures that the ammonia concentration inside the mechanical room does not reach the lower flammability limit.
6. Install ammonia detectors outside the mechanical room and link them to interlock systems that will reduce the quantity of ammonia released to the atmosphere by shutting down pumps and/or compressors, closing remotely operated valves, etc.

Each new risk reduction measure can be evaluated based firstly on its effect on the reduction of the impact distances (through remodeling of the scenarios) and secondly on its associated implementation cost.

The site mentioned in the example above has decided to take action and modify its ammonia refrigeration system to reduce the impact zones. Those modifications included:

1. The reduction of the ammonia inventory by the elimination the high-pressure liquid receiver.
2. The modification of the mechanical room emergency ventilator to an upward instead of a downward venting system.
3. The installation of ammonia detectors on the roof to rapidly detect leaks, interlocked to the pumps and compressors to interrupt the source of the ammonia quickly and automatically.

The revised modeling results for the same scenarios following the above-mentioned modifications appear in the following tables. Note that the 30 minutes AEGL limits were used due to the short duration of the release.

Table 5 – Simulation results for the ¾ inch connection break inside the mechanical room – vertical upward release

1- Leak inside the mechanical room through a broken ¾ inch connection on the high-pressure receiver. Vapors are released to atmosphere outside the building through the emergency ventilation system (vertical evacuation). The release is interrupted by the high concentration interlock inside the mechanical room.		Maximum inventory: 705 kg Operating pressure: 180 psig Mechanical room volume: 35000 cubic feet Ventilation flow rate: 14 500 cfm Height of the ventilation outlet: 37 feet Outside temperature: 25°C Release duration in the room: 60 s		
		Distance to toxic endpoints		
		AEGL 1 - 30 ppm (30 minutes)	*AEGL 2 – 220 ppm (30 minutes)*	*AEGL 3 - 1600 ppm (30 minutes)*
Wind speed (stability) - 1,5m/s (F) (typical night conditions)	Maximum distance at 1m from ground level	Not reached	Not reached	Not reached
Wind speed (stability) - 3,5m/s (D) (typical day time conditions)		1050	**250**	Not reached

A significant reduction of the impact distance can be observed (from 2 000 to 250m) by simply changing the orientation of the fan outlet from horizontal to vertical.

Table 6 – Simulation results for the ¾ inch connection break at the condenser outlet – 60 seconds duration

2- Break of a ¾ connection at the condenser outlet on the mechanical room roof. An ammonia pool is forming, ammonia evaporates and is dispersing into the ambient air. The leak is interrupted after 60 seconds by the detection/interlock system.		Maximum inventory: 705 kg Operating pressure: 180 psig Process temperature: 34,9 °C Direction of release: Horizontal Release elevation from the ground: 37 feet Ambient temperature: 25°C Leak and evaporation duration: 300 s		
		Distance to toxic endpoints		
		AEGL 1 - 30 ppm (30 minutes)	*AEGL 2 - 220 ppm (30 minutes)*	*AEGL 3 - 1600 ppm (30 minutes)*
Wind speed (stability) - 1,5m/s (F)	Maximum distance at 1m from ground level	1 550	310	Not reached
Wind speed (stability) - 3,5m/s (D)		571	Not reached	Not reached

A significant reduction of the impact distances can be observed in this case also.

Table 7 – Simulation results for the ¾ inch connection break on the cold liquid ammonia line – 60 seconds duration

3- Leak from a broken ¾ inch connection on the building roof downstream the cold ammonia pump. The leak is interrupted after 60 seconds by the detection/interlock system.		Maximum inventory: 205 kg Normal operating pressure: 75 psig (pump discharge) Liquid ammonia temperature: -11.5 °C Pump nominal flow rate: 98 gpm Direction of the release: Horizontal Height of the release: 37 feet Ambient temperature: 25°C Leak and evaporation duration: 600 s		
		Distance to toxic endpoints		
		AEGL 1 - 30 ppm (30 minutes)	*AEGL 2 - 220 ppm (30 minutes)*	*AEGL 3 - 1600 ppm (30 minutes)*
Wind speed (stability) - 1,5m/s (F)	Maximum distance at 1m from	2 900	780	Not reached
Wind speed (stability) - 3,5m/s (D)		925	139	Not reached

A significant reduction of the impact distances can be observed in this case also.

The risk reduction measures installed thus significantly reduce the risks for the community while facilitating the elaboration, implementation and communication of the site EEP.

Conclusion

The above discussion highlights the process that should be used to properly assess the emergency planning zones around a site where hazardous substances are present. The site personnel and local emergency responders should then share information and coordinate their efforts to prepare site and community emergency response plans. Joint (or local) emergency planning committees (JEPC or LEPC) are a very useful way to accomplish this task (CRAIM, 2017).

References can be found in the French version