SHELTER-IN-PLACE EFFECTIVENESS IN THE EVENT OF TOXIC GAS RELEASES: FRENCH AND CATALAN ASSESSMENT APPROACH

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ABSTRACT

Origins of toxic gas clouds may be diverse, including accidental releases due to industry or to hazardous materials transportation, or biological or chemical attacks. A protection to such a phenomenon consists in taking advantage of the protection offered by buildings against airborne pollutants. In this event, people can shelter in a building and wait until the toxic plume has gone. European directive concerning major accidents hazards control, known as SEVESO II, requires from Member State's local authorities, to ensure that appropriate measures are taken to guarantee people's protection when located in areas close to Seveso facilities.

In France and in Catalonia, two different political approaches are set to assess the effectiveness of shelter in place in the event of toxic gas releases. This paper exposes and discusses both approaches, including: 1- a brief presentation of the political, legal and technical strategy developed in both countries to face up the imminent risk due to industrial premises, storing and manipulating hazardous materials; 2- a description of the methodology developed in both countries to assess shelter in place effectiveness in buildings; 3- a study case illustrating both approaches in order to assess their consistency.

KEYWORDS

Air infiltration, leakage, shelter-in-place, airflow calculation, vulnerability, toxic releases, outdoor dispersion, dwellings, airtightness

INTRODUCTION

During the last decades, the number of accidents in chemical industries and during transportation of hazardous substances has significantly increased, most of them occurring in inhabited areas. This fact is a huge challenge for local administrations who must minimize risks around industrial facilities where major accidents can occur, and must provide a safe community emergency response in case of accident.

In Europe, following the Seveso accident in Italy, the European Council adopted the SEVESO Directive (EU 85/501/EEC) in 1982, which deal with major accident hazards of certain industrial activities. Later, in 1996, this directive was replaced with the Council Directive 96/82/EC on the control of major accident hazards, known as the Seveso II Directive. Then, in 2003, it was enlarged with the Directive 2003/105/EC. Since 1999, the Directive obligation have been compulsory for industry as well as for the Member States public authorities that are responsible for the implementation and enforcement of the Directive in every country [1]. The legislation considers as potentially dangerous any activities where specified hazardous substances are present in certain quantities. In fact, this Directive classifies industrial facilities that manipulate these hazardous (called Seveso facilities) in two categories, high and low level, depending on the quantity of on-site classified substances.

Major hazards faced by industrial facilities comprise fires, explosions and toxic releases. Fires (i.e pool fire, flash fire, jet fire) are most common, but explosions (i.e BLEVE, confined and unconfined explosion) are more significant in terms of potential damage. Nevertheless, along the history, toxic clouds are recognized for their greatest potential to kill, or injure people and pollute zones for weeks or months. They can affect wider areas than fires or explosions, and may be extremely dangerous in case of released highly toxic substance: the methyl isocyanate Bhopal catastrophe (1984), entailed more than 2500 deaths and 10000 injured people [2][3]. Toxic clouds may originate in direct releases, as a consequence of domino effect or in formation of hazardous compounds as a result of combustion, runaway reactions or unwanted reactions. Article 12 of the Seveso II requires from local authorities of every Member State, to ensure that appropriate measures are taken to guarantee the protection of people living in areas close to Seveso facilities. Hence, the study and assessment of shelter in place effectiveness is of great importance for local administrations: in addition to organize protection of the community in the event of such an accident, they must deal with different urban and land use planning situations (authorization for the implantation of new Seveso facilities, authorization of any substantial change and urban growth in the vicinity of present Seveso facilities) near Seveso facilities [4].

The shelter-in-place (SIP) strategy consists in taking advantage of the protection offered by buildings against airborne pollutants. This protection is based on the fact that the building acts as a barrier that slows down the toxic substance entrance. Therefore, the substance inside concentration would be lower than outside, as well as the toxic load (TL) to which people are exposed. The simplest way of sheltering in place consists in closing all external openings, such as doors and windows, turning off all mechanical ventilation systems and closing openings to reduce outdoor air entrance. So, the only way for pollutant entrance is air infiltration. Then, protection can be improved by seeking refuge in a room with limited air infiltration: 1- seal doors and windows with tape; 2- implement structure modifications to improve the building or an internal room envelope airtightness.

ASSESSMENT OF SIP EFFECTIVENESS: CATALAN APPROACH

Catalunya is a high-industrialized region located in the north-eastern part of Spain, and concerned with numerous high risk level companies according to the Seveso II Directive. Current Catalan legislation regarding the control and planning of severe accidents involving hazardous materials [4][5], requires these facilities to present a risk analysis where different risk zones must be established. In case of toxic gas dispersion, 4 zones are determined: the alert (based on the threshold AEGL-1, [6]), the intervention (based on the AEGL-2), the lethal area of 1% and the fourth zone corresponding to a 0.1% lethal dose inside buildings, when taking into account the implementation of shelter in place. The fourth zone is used to delimit the evacuation area (the evacuation radius). It requires the estimation of indoor concentration (C_i) and indoor toxic load (TL_i). The methodology currently used by the Catalan Government considers several factors such as the involved substance, the site conditions, the cloud duration, and the air infiltration exchange rate (ACH), considered as constant. However, the use of a fix ACH, does not take into account neither, buildings' airtightness distribution in the affected area, nor the ACH distribution under prevailing and worst meteorological conditions, which can lead to under or overestimate the real evacuation radius [7].

In this paper, we used a simplified methodology (see method 1 in Figure 1), proposed by Montoya [8]. It includes the estimation of airtightness distribution in the affected area depending on buildings' features and meteorological conditions, as described below:

1. Define source term conditions: meteorology, data related to substance properties.

2. Estimate outdoor gas dispersion and establish the affected zone.
3. Create a grid over this zone and identify the census tracts involved.
4. Calculate the airtightness (c') distribution by census tract using the UPC-CETE airtightness model [8].
5. Compute the *ACH* by census tract, using the AIM-2 ventilation model and the 100th percentile of c' distribution.
6. For each grid cell, compute C_i and TL_i profiles using the *ACH* of the cell's census tract.
7. Estimate the casualty probability for each grid cell, through the Probit analysis, and establish the evacuation radius, i.e the largest distance between the source and the last downwind cell with a casualty probability of 0.1%.

In addition to closing all ventilation openings and turning off the mechanical ventilation systems, people can increase the protection level by seeking shelter in an indoor room. In that case, Montoya et al. [9] found that the indoor shelter *ACH* when sealed; consists approximately in a 35% reduction of the dwelling *ACH*. However no structural works on shelter are performed, in order to improve building or indoor room airtightness.

ASSESSMENT OF SIP EFFECTIVENESS: FRENCH APPROACH

In France a prevention strategy based on mandatory works in an inner room is being implemented. People should seek refugee in such a room and be protected during 2 hours against irreversible effects while the toxic cloud passes away. It applies to existing and future buildings located near Seveso II facilities. Local land-use plans, named technological risk prevention plan (PPRT) [10], specify airtightness requirements for such shelter inside dwellings. However, buildings, when very close to the toxic site, when the risk is very high, could be expropriated.

This second methodology (see method 2 of Figure 1) is based on abacus we elaborated with CONFINE [11], assuming that every dwelling can be modeled as a standard 3-zones dwelling (Figure 2) with a default envelope airtightness level (Q_{4Pa_surf}, the airtightness indicator in French Thermal regulation [12]) estimated from the CETE airtightness database[1] (the 95th percentile).

The method is described here below:

1. Define the PPRT impacted area, based on the safety report supplied by the operator (list of all the possible dangerous phenomena, their probability and the forecast intensity of their effects).
2. Define different zones along with the intensity of the aggression (irreversible, lethal 1%, or lethal 5% effects) and on the types of pollutants. For each zone, a conventional toxic cloud (60 min duration) is also defined.
3. Select the abacus corresponding to the meteorological conditions used for precedent zoning. Extract the shelter airtightness requirement (n_{50},[12]), corresponding to this conventional toxic cloud, and to the limit indoor concentration (French threshold is close to AEGL-2 120 min). Abacus are drawn for down and upwind shelters.
4. For each zone, inscribe those shelter airtightness requirements into the final PPRT-plan.

Contrarily to non-residential buildings, there is no need to use a modeling software such as CONFINE to define the shelter airtightness level of dwellings.

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[1] 402 dwellings in 2007

PERFORMANCE OF BOTH APPROACHES: A STUDY CASE

In order to assess the consistency of both scientific approaches, we realized a comparative study described in Figure 1. It consists in determining the evacuation radius with method 1. Then, according to method 2, for a standard single family dwelling located at different points inside and outside the evacuation radius, we estimate through CONFINE the required airtightness for a limit indoor concentration equal to AEGL-3_30 min. If the required airtightness value is lower than the representative airtightness value taken from the SIP-CETE database[2] (e.g. the 90th or 50th percentile of the distribution, which would represent the probable airtightness level of the shelters in the zone), the conclusion is that sealing works are needed in order to achieve a safe shelter. On the contrary, if the required airtightness value is higher than the representative airtightness, the dwelling provides a safe shelter. Our study case comprises a 60 t chlorine release from a storage tank. For the calculations, we considered an industrial area site with a ground roughness (z_o) of 0.3 m, 15ºC of temperature, a 4 m/s wind speed and neutral stability (4D).

Results obtained

Following the above mentioned steps, the application of method 1 gave an evacuation radius of 2700 m. Outside, shelter-in-place is implemented. Therefore we selected 5 points downwind the release source: 1200, 1800, 2400, 2700 and 3200 m. For each location, we estimated the airtightness level needed to provide a safe environment for a shelter in a standard dwelling. The required airtightness value was calculated using CONFINE for two different shelter situations: upwind and downwind. As can be seen in Table 2, we can firstly observe that downwind shelters are more protective. Then, for the 50th percentile of the SIP-CETE airtightness database, shelters in both situations, downwind and upwind, are protective for a distance over 2700 m, the evacuation radius estimated with method 1. On the contrary, when the representative airtightness level was assumed to be the 90th percentile of the SIP-CETE airtightness database, only downwind shelters provided a protected environment for 2700 and 3200 m. In this case, upwind shelters with this same airtightness level would require structural sealing works. From these results, carried on only one case study, we can say that equivalent results between both methods were obtained when assuming the representative airtightness level as the 50th percentile. If assuming the 90th percentile as the representative airtightness value method 2 is more conservative than method 1.

CONCLUSION

This paper gave a brief description of both French and Catalan strategies to comply with the Seveso II Directive in their territory. We have assessed the consistency of two scientific approaches, one used in France and the other proposed for Catalonia, to face up the risk due to a toxic cloud, considering shelter in place as a protection measure. We found a complete coherence between both approaches when the 50th percentile of the SIP-CETE airtightness database was used as the representative airtightness level for shelters in the zone. However, the small size of the SIP-CETE database and the differences in construction techniques may affect the extreme values of the distribution. Therefore more work is needed, both in France and Catalonia: 1- to obtain, experimental data on building airtightness and *ACH* measurements, especially on internal rooms; 2- to carry many more case studies in order to specify the most convenient airtightness level percentile.

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[2] 39 shelters in 2011, this database has just been started in July 2011

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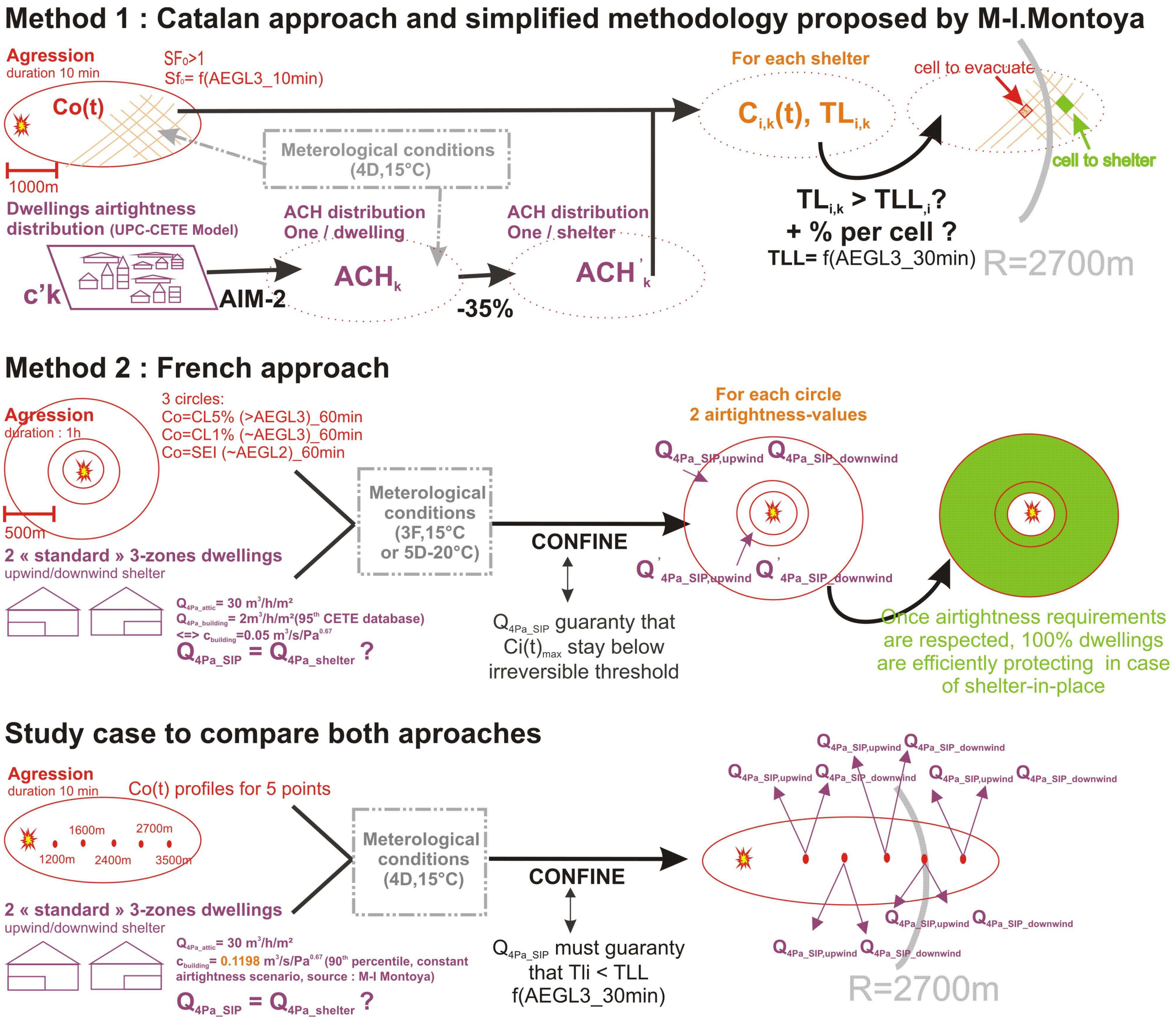
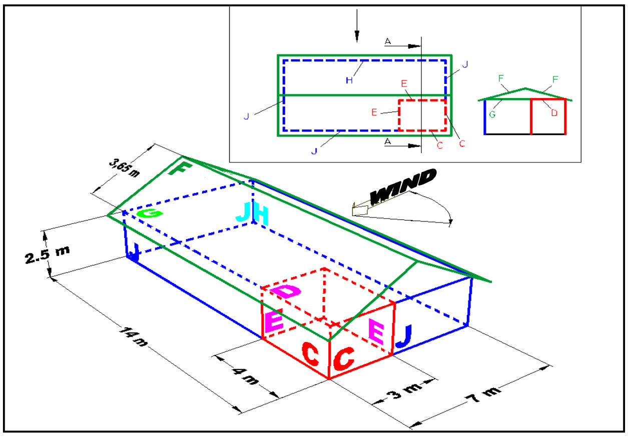


Figure 1 : Description of the different approaches to assess shelter in place effectiveness



$V_{shelter}$ (m^3)	27
V_{attic} (m^3)	98
$V_{rest\ of\ the\ building}$ (m^3)	251
$H_{building}$ (m)	4.2
Slope of the roof (°)	25
$Q_{4Pa\_Surf,attic}$ (m^3/h/m²)	30
$Q_{4Pa\_Surf,building}$ (m^3/h/m²)	2

Figure 2 and Table 1 : Characteristics of 3-zones "standard single-family dwelling", with downwind shelter considered in France

Location (m)	**Conclusion method 1**	**Standard dwelling**	**Shelter airtightness required n_{50} (h^{-1})**	**Conclusion based on the n_{50} (90th)*: 13,3 h^{-1}**	**Conclusion based on the n_{50} (50th)*: 8,3 h^{-1}**
1200	Evacuation	Downwind	9,0	sealing works	sealing works
		Upwind	2,0	sealing works	sealing works
1800	Evacuation	Downwind	14,8	protected	Protected
		Upwind	3,2	sealing works	sealing works
2400	Evacuation	Downwind	34,0	protected	Protected
		Upwind	6,7	sealing works	sealing works
2700	Shelter in place	Downwind	46,0	protected	Protected
		Upwind	8,6	sealing works	Protected
3200	Shelter in place	Downwind	84,2	protected	Protected
		Upwind	12,9	sealing works	Protected

* The n_{50} correspond to the 90th and 50th percentile of the SIP-CETE airtightness database, respectively.

Table 2. Results obtained from comparative study

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